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Circular Polarized Transparent Antenna for 5.8 GHz WLAN Applications

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Abstract—A novel design for a transparent circularly polarized circular slot antenna fed by a coplanar waveguide (CPW) is presented in this paper. The circular polarization is achieved by introducing a tapered split gap in the ring patch of the circular slot antenna in combination with unequal CPW ground arms. The antenna is designed using AgHT-4 laminated on a 2 mm thick glass with a relative permittivity of 7. The proposed antenna is designed to operate at 5.8 GHz for WLAN applications. The tapered split gap and inequality in the lengths of the CPW ground arms contribute to a 3 dB axial ratio bandwidth from 5.4 to 6.2 GHz. The proposed antenna has been studied theoretically and fabricated. The measured results show that the proposed antenna has a gain of 0.92 dB at 5.8 GHz. Reflection coefficient (S_{11}), axial ratio (AR), and radiation patterns are presented and briefly discussed.

1. INTRODUCTION

There has been a sizeable amount of research conducted in the last two decades on optically transparent antenna design, enabling it to be deployed on see-through surfaces. Such antennas could thus be discreetly installed anywhere without many design issues. One of the several options is to use transparent conductive films, such as indium tin oxide (ITO), fluorine-doped tin oxide (FTO) and silver coated polyester (AgHT) films, which act as conducting elements by allowing electric currents to flow through while maintaining optical transparency [1]. A simple low-cost and conformal patch antenna could be designed using these films. With a thin profile and see-through features, this type of antenna can be incorporated on flat surfaces such as glass and mirrors of buildings and automotives where aesthetical value is ever so important [2].

A trade-off that must be considered on these conductive films where transparency has to be sacrificed for better conductivity. Lower than 70% transparency has been recorded for AgHT to have an effective conductivity [3] that is enough to ensure good antenna performances, and based on this, various antenna designs have been reported for UWB [4, 5] and frequency dependent applications [6]; however, most of them are linearly polarized (LP).

Past studies have proven that the challenges of optically transparent patch antennas include the inability of achieving high gains (more than 2 dB) and reduced efficiencies of microstrip antennas, compared to antennas that are not near ground plane [7]. To obtain distance gain, the use of circular polarization (CP) is advantageous because of its ability to strive in high reflective, multipath and line-of-sight scenarios compared to LP [8]. It is also a challenge to generate CP using transparent conductive oxides (TCO) as conductivity has to be sacrificed in order to achieve transparency high enough to be aesthetically used in the industry. It is for such a reason that drives the author to pursue this study.

Two techniques have been investigated on CP patch antennas; single [9] and dual feed [10]. AR bandwidth is narrower on a single feed, despite the simplicity in the feeding design. Dual feed can produce a larger AR bandwidth, but the structure is more complex [11].

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In this paper, a novel single feed transparent CP antenna is introduced for 5.8 GHz WLAN applications. The design incorporates unequal CPW ground arms and a ring patch radiator with a tapered split gap at the top right or 2 o'clock orientation; both design features are essential in attaining circular polarization. To the authors' best knowledge, this is the first transparent antenna that incorporates a combination of such features to achieve circular polarization.

2. ANTENNA DESIGN

The geometry and photograph of the fabricated antenna are shown in Figure 1. The antenna is designed on a simple glass substrate with a relative permittivity of 7 and a thickness of 2 mm. The size of the glass substrate is designed large enough ($90 \times 60\,\mathrm{mm}^2$) so that the antenna properties, including gain, can be stabilized and not change after increasing the dimensions of the glass substrate [3, 12].

The radiating element is made from a material called AgHT-4 and has dimensions of $25 \times 22.37\,\mathrm{mm}^2$, which occupies only a small portion of the glass substrate's surface. The conductive portion of the AgHT-4 has a DC resistance of $25\,\Omega$ and a conductivity of 220,000 S/m [2]. The surface resistivity of the AgHT-4 as noted from its trademark name is $4\,\Omega/\mathrm{m}^2$. The AgHT film has a thickness of 0.175 mm making it suitable for use on glass of windows and buildings.

The microstrip ring patch with a tapered split gap is constructed in the middle of a partially enclosed and extended ground of the CPW. The sharp edges at every corner in the inner part of the CPW are replaced with a curve, for a better reflection coefficient (S_{11}).

The ring patch with outer radius of 5.264 mm and inner radius of 3.264 mm is fed by a feed line of width 1.51 mm. The feed gap between the feed line and CPW ground is 0.432 mm. The dimensions of the geometry are shown in Figure 1 and indicated in Table 1.

(a) (b)

Figure 1. Layout of the circularly polarized transparent antenna. (a) 3D representations with dimensions. (b) Fabricated transparent antenna.

Table 1. Dimensions of the antenna.

Parameter	Value (mm)	Parameter	Value (mm)
Ha	25	f	1.51
Wa	22.374	W	2
Hg	10	C	3
Wg	10	r_1	5.264
Hf	9.736	r_2	3.264
Wg_2	10	Glass thickness	2
		α	13.77°

The differences in the lengths of the CPW arms are to provide the phase difference. The right arm is 0.425λ longer than the left arm causing the electromagnetic waves flowing in the arms to undergo a relative phase difference. By taking advantage of this phenomenon, a phase difference of 90° is pitched and CP is achieved [9]. However, the purity of the AR is found to be poor, and hence a tapered split gap of angle α is introduced in the ring patch to cause a disproportionate current flow and to consequently improve the AR. The numerical analysis and the optimization of the proposed antenna are performed using CST Microwave Studio 2012 simulation software.

3. MATHEMATICAL EXPLANATION

Since the dimension of the patch is treated as a circular loop, the actual radius of the patch is given by Equation (1) where F is gotten from (2) [13]

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{1/2}} \quad (1)$$

$$F = \frac{8.791 \times 10^9}{f_r\sqrt{\varepsilon_r}} \quad (2)$$

Equation (1) does not take into consideration of the fringing effect. Since fringing makes the patch electrically larger, the effective radius of patch is used and is given by

$$a_e = a\left\{1 + \frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{1/2} \quad (3)$$

AgHT is composed of a thin layer of silver sandwiched between two layers of tin oxide coated on to a film of PET. Under normal circumstances, PET layer itself can act as a substrate which carries a relative permittivity of 3.228. Since this antenna design is deployed on top of a glass substrate which carries an entirely different value of relative permittivity, an equivalent relative permittivity must be used in order simplify the analysis of the patch microstrip antenna with multi-layer substrates which is given by [14].

$$\varepsilon_{req} = \left(\sum_{n=1}^{N}\frac{t_n}{\varepsilon_{rn}}\right)^{-1} \cdot \left(\sum_{n=1}^{N} t_n\right) \quad (4)$$

where t_n is the height of the nth substrate layer and ε_r the relative permittivity of the nth substrate layer. The height of the equivalent substrate is taken to equal the total height of the substrates and is given by

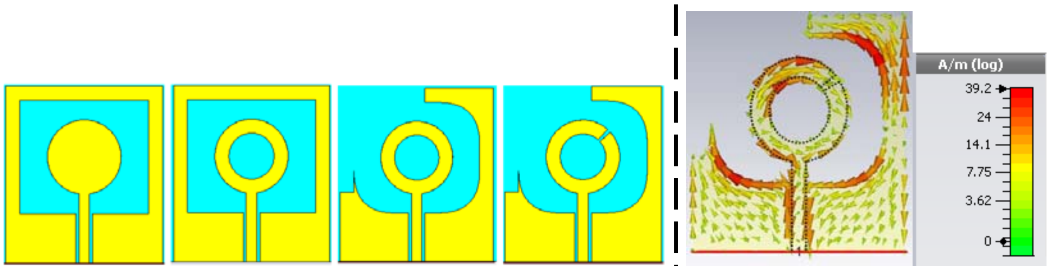
$$t_{eq} = \sum_{n=1}^{N} t_n \quad (5)$$

Based on these equations, an equivalent relative permittivity of 3.36 is obtained for a PET layer of relative permittivity of 3.228, laminated on a glass layer of relative permittivity of 7.

4. PARAMETRIC STUDIES

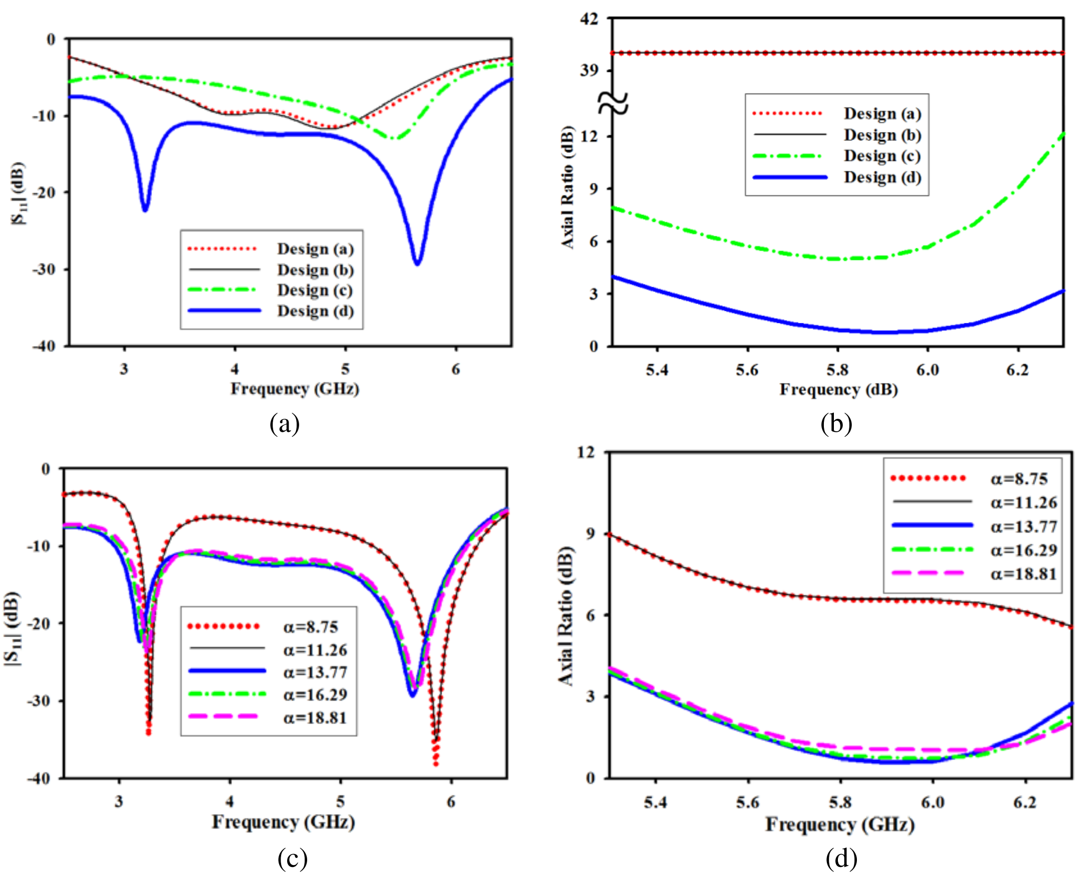
The proposed antenna is investigated in several configurations as shown in Figures 2(a)–(d). At first, a circular patch with an extended ground surrounding it was designed. The radius of the patch is calculated based on the equations discussed in Section 3 earlier. A slot is introduced (Figure 2(b)), but no changes can be seen on reflection coefficient (Figure 3(a)). Since both of these configurations by design observation are linearly polarized, the result of the axial ratio is not significant. However, by cutting the arms of CPW to vary their lengths and introduce curves and a tapered split of angle, α, in the patch ring, AR and reflection coefficient results have been improved to values of 0.9 dB and −19 dB at 5.8 GHz, respectively, and these can be observed from Figures 3(a) and (b).

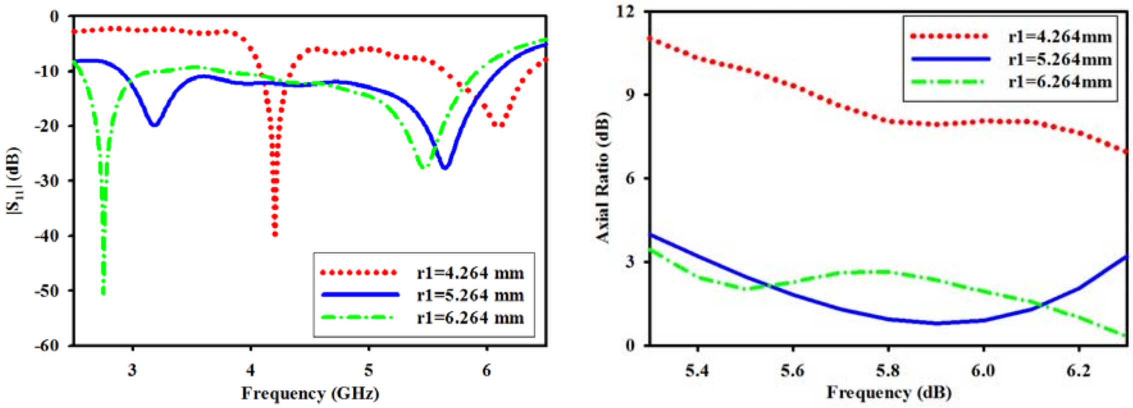
Varying the gap of the tapered split by varying angle, α, as depicted in Figures 3(c) and (d), gives excellent reflection coefficient response at α of 8.75° and 11.26° but however degrades the AR. Taking both reflection coefficient and AR value into consideration, α of 13.77° was chosen as it gave the most satisfying result. Since the tapered split gap proves to be crucial in attaining CP, surface current distribution is shown in Figure 2(e), with the introduction of tapered slit gap. The current density is equally distributed at the ring patch without the split gap, thus reducing the CP quality as seen in Figure 3(b). Introduction of the split gap created a disproportion in electric current flow, causing an increase in the AR value by 5 dB over that obtained without the gap. The outer radius, r_1 of the ring patch, is then parametrically investigated to get the optimum result for CP at 5.8 GHz. From Figure 3(e), as r_1 was increased from 4.264 mm to 6.264 mm (with a corresponding 1 mm increase in r_1),



(a) (b) (c) (d) (e)

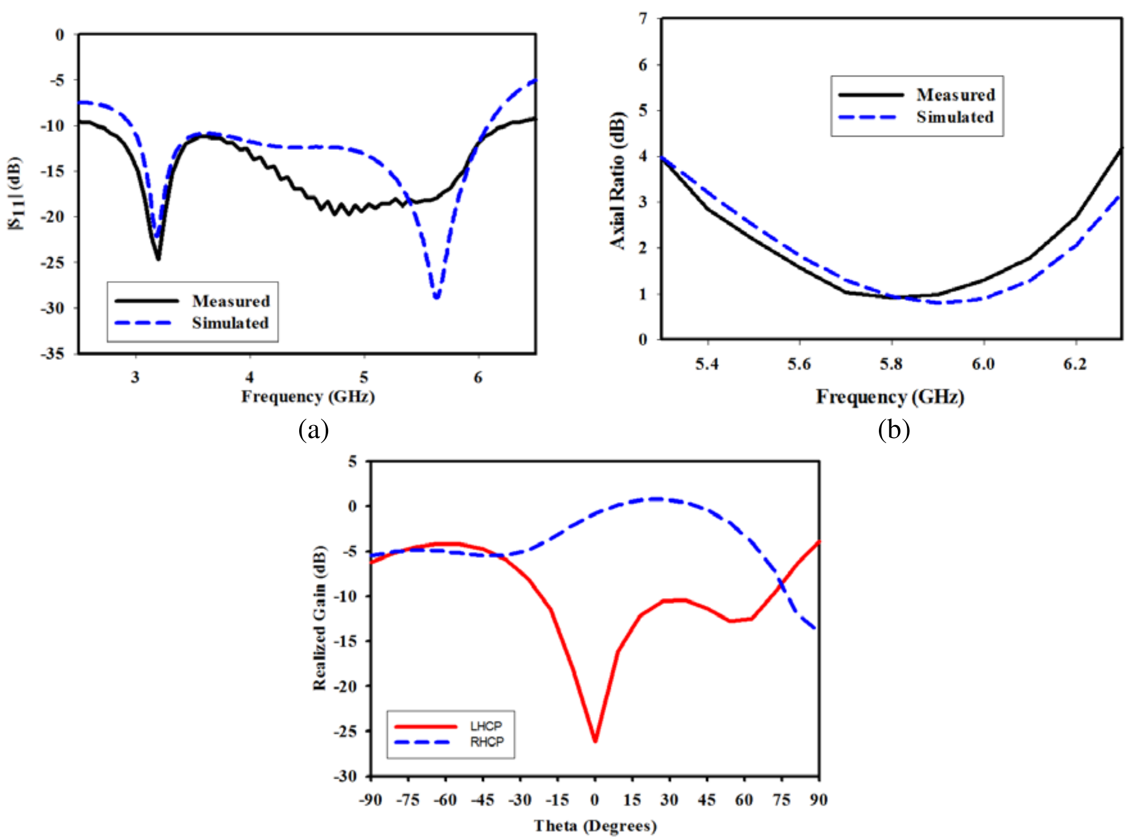
Figure 2. Different configurations of the proposed antenna, (a) circular patch design with extended CPW; (b) introduction of a slot in the circular patch to create a circular slot antenna; (c) modification to the CPW grounds; (d) insertion of a tapered split of angle, α on the ring of the circular slot antenna; and (e) surface current distributions of the circular slot antenna with tapered split gap.





(e) (f)

Figure 3. Simulated (a) S_{11} and (b) axial ratio as the antenna physical configuration is changed. Simulated (c) S_{11} and (d) axial ratio as gap angle width, α is varied. Simulated (e) S_{11} and (f) axial ratio patch outer radius, r_1 is altered.



(a) (b) (c)

Figure 4. Comparison of the simulated and measured, (a) reflection coefficient and (b) AR of the proposed antenna; (c) Measured LHCP and RHCP.

reflection coefficient was seen to vary from −20 dB to −30 dB which are all acceptable; however, it is not so in the case of AR. There are only two AR values that fall below 3 dB, and these are when r_1 equals 5.624 or 6.624 mm. Such results are triggered by proper impedance matching, and from Figure 3(f), it is obvious that r_1 of 5.624 is a better value for CP.

5. RESULTS AND DISCUSSION

Figures 4(a) and (b) show the final simulated and measured S_{11} and AR of the transparent CP antenna, and they are in good agreement. The proposed antenna obtained a wideband reflection coefficient response from 2.55–6 GHz which covered the desired 5.8 GHz band for WLAN applications. A 3 dB AR bandwidth of 800 MHz from 5.4–6.2 GHz is correspondingly observed at 5.8 GHz as depicted in Figure 4(b). The measured peak gain of the proposed antenna at 5.8 GHz is 0.92. It must be noted that such a number is normal for AgHT-4 as its conductivity is almost 30 times lower than aluminum [15].

The measured radiation patterns of the fabricated prototype, right-hand CP (RHCP) and left-hand CP (LHCP) gains at 5.8 GHz for x-z planes are shown in Figure 4(c). From the observation, RHCP field component is stronger than the LHCP counterpart about 25 dB in the broadside directions, so this proposed design is considered as right-handed CP transparent antenna.

6. CONCLUSIONS

In this paper, a right-handed circularly polarized transparent antenna operating at 5.8 GHz has been simulated and fabricated. The proposed transparent antenna delivers a reflection coefficient response of −13 dB and a 3 dB AR bandwidth of 800 MHz from 5.4 to 6.2 GHz at 5.8 GHz, respectively. The transparent antenna has a gain of 0.92 dB because of the low conductivity of the AgHT material. The proposed transparent antenna is suitable to be used on windows and windshield of automotive vehicles and also other flat surfaces without affecting their visibility or aesthetics.

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