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REGULAR ARTICLE

A Compact T-Shaped Circular Patch Antenna For C-Band Applications

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A novel dual-band T-shaped circular patch antenna (CPA) for C-band applications is designed and analysed in this article. This antenna can function in two different resonating frequencies, making the antenna appropriate for C-band wireless applications. A microstrip transmission line having an impedance of 50 Ω is utilised to feed the CPA. T-shaped CPA presents an evolution process based on a typical circular patch antenna (CPA). A finite element method-based software An-soft HFSSv13 has been utilized to extract the simulated results pertaining to radiation patterns, gain, VSWR and reflection coefficient to validate the design concept. T-shaped CPA is designed utilising polyimide substrate with ε_r of 3.5, a height of 0.1 mm, and overall sizes of only 38 × 30 mm², which is compact in size when compared with the existing circular patch antennas. T-shaped CPA is operating over the desired bands ($S_{11} \leq -10$ dB) are 5.2 GHz and 6.8 GHz. 3 dBi gain of 3.1 dBi has been observed at both the resonating frequencies of the T-shaped CPA. The antennas compact design and the results obtained make them highly recommended for usage in C-band wireless communication applications.

Keywords: T-shaped Circular antenna, Microstrip patch antenna, Flexible substrate, HFSS, C-band Applications.

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1. INTRODUCTION

Compact antenna designs are becoming more and more necessary in the quickly changing field of wireless communication, particularly for C-band wireless communication applications. The need for antennas that perform effectively across a range of frequency bands while maintaining a small size is become more essential as these technologies develop [1]. Wireless applications require multiband antennas with exceptional radiation characteristics and a broad impedance bandwidth to meet their demands across a wide range of frequency ranges over S-band as well as C-band [2]. An important consideration in the design of small antennas is the feeding structure. CPW and MS transmission lines are often utilized feeding techniques in printed antenna designs [3]. Antenna engineers have recently come to favour asymmetrical coplanar strips (ACSs), which have a single lateral ground plane rather of the twin lateral grounds present in CPW lines. This design strategy, which uses an ACS structure, preserves concepts comparable to those of coplanar transmission lines while enabling a compact antenna (about 40 % smaller than its equivalent CPW structures) [4]. A dual-band monopole antenna is designed by utilising circular fractal elements and feeding of an antenna is given through CPW feed [5]. Dual working bands of 3.15 to 3.75 GHz and 5.02 to 7.58 GHz are provided by this design by inserting particular slot combinations in the radiator. Excited by a CPW feedline, a 22 × 22 mm² pentagonal ring fractal antenna is demonstrated in [6] to attain two frequency bands (3.12-3.82 GHz and 5.16-5.83 GHz) with resonances at around 3.4 and 5.5 GHz, respectively. In [7], a fractal monopole antenna with a band-notched design and a 9-point star form is described. Its ground planes are equipped with two L-shaped slots that enable it to function efficiently in two distinct frequency ranges: 3.05 to 3.84 GHz and 5.15 to 5.825 GHz. However, at 30 × 45 mm², it is quite enormous. In [8], a semi-circular microstrip antenna with a folded U-shaped slot inside the patch and a tapered ground plane is shown. Its dimensions are 17 mm × 18 mm, and its operating frequencies are 3.4 GHz-3.7 GHz and 5.725 GHz-5.875 GHz. A wideband antenna inspired by metamaterials and fed by CPW was described in [9]. With a broad bandwidth of 3.06 GHz to 5.89 GHz, the antenna is appropriate for WiMAX and WLAN applications. A circularly-slotted antenna with full ground plane is described in [10] in order to achieve the intended dual-band functioning. The third iteration of the pentagonal Sierpinski gasket island was used in [11] to create a fractal antenna for use in 5.2 GHz WLAN and 3.5 GHz WiMAX. In [12], a CPW-fed antenna patch in the shape of a rupee and measuring 17.5 × 17.5 × 1.6 mm³ was described. By add-

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ing an extra horizontal L-shaped strip, the developed antenna achieves a dual-band characteristics. Many microstrip antenna designs have been put presented to design an antenna that can handle multiband and broadband operations. In [13], a WiMAX and WLAN ACS-fed L-profile double-band monopole antenna design was introduced. With an area reduction of about 44 %, it was developed in three evolution stages from its counterpart, the CPW fed antenna. In [14], a monopole antenna with a hook shape that is fed by the ACS structure was suggested. The antenna employed a $\lambda/4$ with a C-shaped half wavelength loop strip to create two independently controllable frequency bands with centres at 3.5 and 5.2 GHz. In [15], a second dual-band planar antenna with an area of 21 × 15.35 mm^2 that is fed by an ACS was built. The antenna functions at two different frequencies of 3.5 GHz and 5.5 GHz, which correspond to the WiMAX and WLAN bands, respectively, by utilizing defected ground and defected microstrip structures. A compact MIMO antenna has been designed and analysed for UWB applications [16]. The above-mentioned antennas are too big, have complex structures, or have a narrower upper frequency band, which makes them unsuitable for portable communication devices even though they are made to efficiently fulfil the necessary C-band wireless communication applications.

From the explanation above, dual-band antennas with small size, acceptable radiation characteristics, and a simple geometrical design are still needed. Consequently, a T-shaped CPA with full ground fed by microstrip transmission line is presented in this document. The low-cost, 0.1-mm thick Polyimide substrate used to design the T-shaped CPA and it occupies an area of 38 × 30 × 0.1 mm^3. The performance of antennas, including the radiation patterns, gain, VSWR and reflection coefficient was simulated using HFSS modelling tool. Section 2 goes into great detail about the designs of T-shaped CPA and their structures. Section 3 presents the results obtained from the simulation software. Section 4 provides the conclusion.

2. DESIGN & ANALYSIS OF T-SHAPED CPA

2.1 Evolution Process

Here, a thorough design evolution process is covered to demonstrate how a reference antenna CPA was first designed with predetermined specifications (resonance frequency f_r, substrate height h_s, as well as the dielectric constant ε_r. After that, CPA is subjected to four design processes until the suggested antennas reach the intended operating dual frequency bands with small dimensions. The impact of structural changes on the T-shaped CPAs reflection coefficient and VSWR is depicted in Figure 2. The following is a discussion of these design steps. Figure 1 display the iterative based design of the T-shaped CPA. In first iteration a circular patch having a radius of 11 mm is attached to the monopole with full ground plane. Second iteration by subtracting a circle having a radius of 10 mm from the iteration 1 antenna. A circle having a radius of 8 mm is united to iteration-2 antenna in iteration 3. Iteration 4 is obtained by subtracting a 6-mm radian circle from iteration 3 antenna. Iteration 5 is the final iteration and it is obtained by attaching a T-shaped structure having a length of 6 mm and width of 2mm to the iteration 4 antenna. In conclusion, it is shown that adding more resonant structures to the antenna would effectively give previously unattainable degrees of freedom for regulating the higher frequency band with a minor impact on the lower band, all while preserving antenna compactness. Therefore, when building multiband antennas with small diameters and straightforward construction, this feature may be more appealing. The mathematical formula that are utilised in designing the T-shaped CPA are mentioned below.

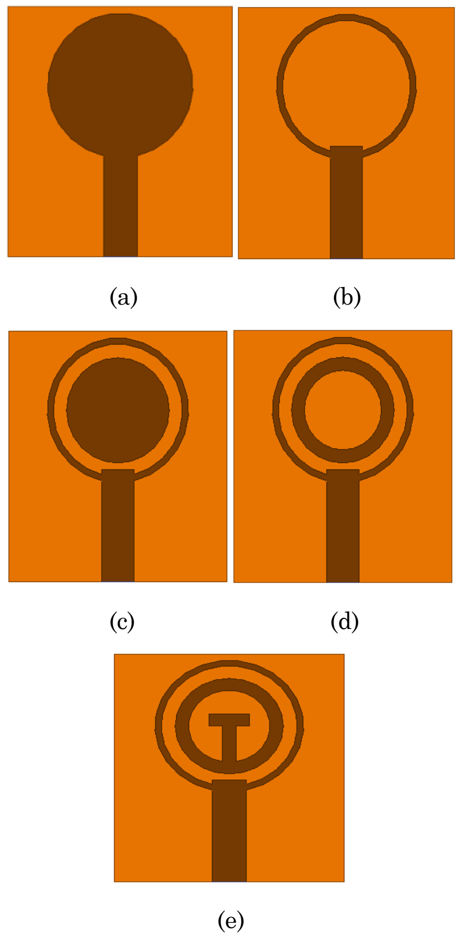
$$L = \frac{C}{2F_r\sqrt{\varepsilon_{reff}}} - 2\Delta l \tag{1}$$

$$a = \frac{F}{\sqrt{1+\frac{2h}{\Pi\varepsilon_r}[\ln\left(\frac{\Pi f_r}{2h}\right)+1.7726]}} \tag{2}$$

$$F = \frac{8.791*10^9}{f_r\sqrt{\varepsilon_r}} \tag{3}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+\left[\frac{12h}{w}\right]\right]^{-1/2} \tag{4}$$

In the circular patch, a stands for the radius, which is found using equation (2), and L stands for the patch's length, which is acquired using (1). The variable h indicates the material's thickness. F is generated from the application of equation (2). f_r stands for the substrate's centre frequency.



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

Fig. 1 – Evolution procedure of the T-shaped CPA

Figure 2 represents the reflection co-efficient of the T-shaped CPA at all the iterations. First iteration is obtained by attaching a circular patch having a radius of 11 mm to the monopole with full ground plane. Iteration 1 antenna is resonating at 6.8 GHz and it offers S_{11} of – 16.47 dB. Second iteration by subtracting a circle having a radius of 10 mm from the iteration 1 antenna. Iteration 2 antenna is resonating at 6.8 GHz and it offers S_{11} of – 25.8 dB. In iteration 3 a circle having a radius of 8 mm is attached to iteration-2 antenna. Iteration 3 antenna is resonating at 6.8 GHz and it offers S_{11} of – 48.1 dB. Iteration 4 is obtained by subtracting a 6-mm radian circle from iteration 3 antenna. Iteration 4 antenna is resonating at 4.4 GHz and 7.8 GHz and it offers S_{11} of – 21.9 dB and – 24.8 dB respectively. Iteration 5 is the final iteration and it is obtained by attaching a T-shaped structure having a length of 6 mm and width of 2 mm to the iteration 4 antenna. Iteration 5 antenna is resonating at 5.0 GHz-5.20 GHz and 6.80 GHz and it offers S_{11} of – 39.1 dB and – 24 dB respectively. These results make the T-shaped CPA suitable for C-band wireless communication applications.

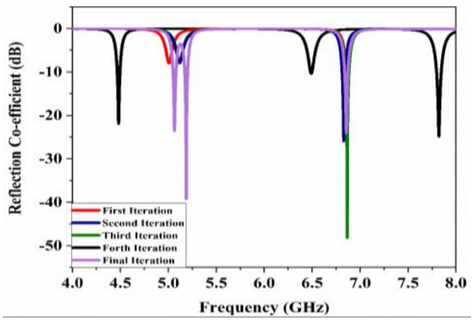


Fig. 2 – Obtained S_{11}(dB) of the T-shaped CPA

2.2 Analysis of T-shaped CPA

Figure 3 depicts the T-shaped CPAs suggested geometry and design. Table 1 displays the T-shaped CPAs design specifications. The Polyimide substrate, which has a thickness of 0.1 mm, a tanδ of 0.008 and a 3.5 ε_r, is used to design the T-shaped CPA. A 50 Ω microstrip transmission line connects the T-shaped CPA which features a full ground plane and measures 38 × 30 × 0.1 mm^3. FEM tool HFSS is used to simulate T-shaped CPA. The antenna dimensions are simulated and optimized using HFSS based on these parameters and considerations. By altering the length, radius and width the antenna, the resonant frequencies can be changed. Accordingly, for C-band applications, a T-shaped CPA is designed on the top surface of the antenna and the bottom surface is full ground plane. The top and bottom views of T-shaped CPA are illustrated in Figure 3.

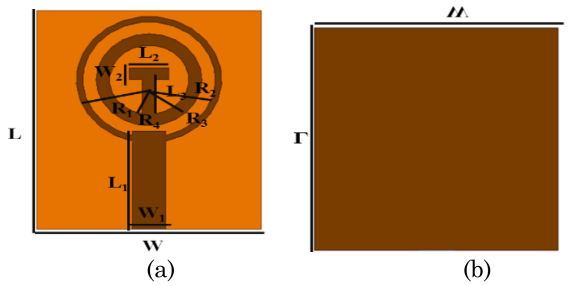


Fig. 3 – T-shaped CPA (a) Top surface (b) Bottom surface

Table 1 – Measurements of T-shaped CPA

Parameter	Values (mm)
L	38
W	30
L_1	17
W_1	5.05
L_2	2
W_2	2
L_3	6
R_1	11
R_2	10
R_3	8
R_4	6

3. RESULTS AND DISCUSSIONS

Bandwidth and gain of the traditional microstrip line-fed antenna are narrow. Figure 4 represents reflection co-efficient and VSWR of the T-shaped CPA. T-shaped CPA is resonating at 5.0 GHz-5.20 GHz and 6.8 GHz and it offers S_{11} of – 39.1 dB and – 24 dB respectively This antenna is a solid choice for C-band applications due to its small size. It has been noted that the suggested antenna iterations greatly enhance antenna performance. Figure 4 compares how S_{11} varies with frequency for the proposed and conventional geometry. VSWR values are plotted in Figure 4 over a frequency range of 4.0 GHz to 8.0 GHz. The X-axis displays the frequency in GHz, and the Y-axis on right side displays the VSWR value and left side displays reflection co-efficient. The VSWR value is lowest at 5.0 GHz-5.20 GHz and 6.80 GHz where it offers to about 1.1 and 1.4 respectively. Figure 5 displays the overall gain plotted in three dimensions. While the color bar on the left displays the antenna's total gain in dB, different colours correspond to different gain levels. The plot's maximum overall gain of 3.1 dB is outstanding. Current distribution of T-shaped CPA is shown in Figure 5. The largest field distribution is represented by the color red. 50 Am-1 is the highest value that has been noted. The distribution of surface current in the T-shaped CPA is crucial in determining the radiation zones; red indicates locations with the highest radiation intensity. The antenna's core and edges exhibit the maximum radiation intensities, as seen in Figure 6.

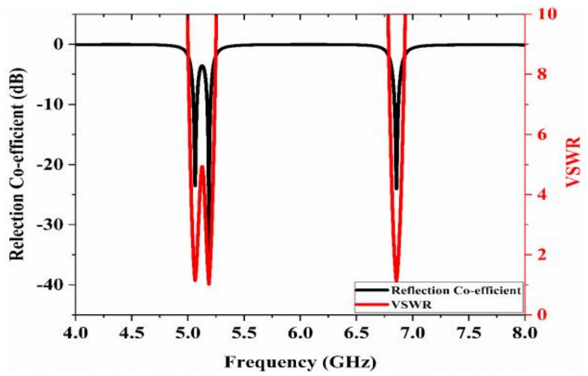


Fig. 4 – Reflection Co-efficient and VSWR of the T-shaped CPA

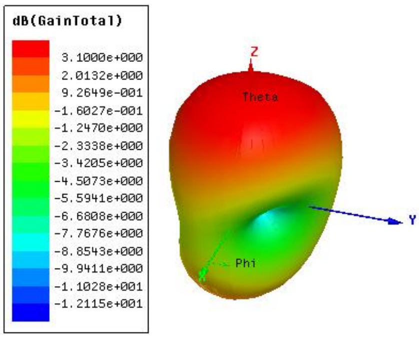


Fig. 5 – Obtained 3D Gain of the T-shaped CPA

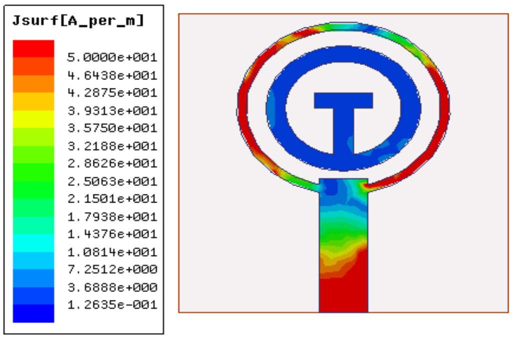


Fig. 6 – Surface current distribution of the T-shaped CPA

Table 2 shows a comparison of the T-shaped CPA with a few previously published antennas. According to the analysis, the intended dual working bands are covered by the peak gain achieved by the proposed antenna. Furthermore, compared to many of the published counterpart antennas, the antenna presented in this work is smaller. Additionally, the T-shaped CPA is an ideal candidate for C-band wireless communication applications, because the planned antennas lowest reflection co-efficient and peak gain are sufficiently high to be acceptable.

Table 2 – Comparison table for T-shaped CPA with the avalialable Literature

Ref.	**Feeding Method**	**Antenna size (mm²)**	**Gain (dBi)**	**VSWR**	**S_{11} (dB)**
[6]	CPW	22 × 22	2.04	1.02	– 18
[7]	CPW	30 × 45	2.63	1.4	– 16
[8]	CPW	17 × 18	2.05	1.22	– 24
[10]	CPW	40 ×30	3	1.5	– 22
This work	Microstrip line (Edge feeding)	38 × 30	3.1	1.1 1.4	– 39.1 – 24

4. CONCLUSION

To verify the proposed design, the simulated results for radiation patterns, gain, VSWR, and reflection coefficient were extracted using the software An-soft HFSSv13, which is based on the finite element approach. With a height of 0.1 mm, ε_r of 3.5, and an overall size of only 38 × 30 mm², the T-shaped CPA is supposed to be more compact than the current circular patch antennas. The target bands ($S_{11} \leq -10$ dB) that the T-shaped CPA operates over are 5.2 GHz and 6.8 GHz. 3 dBi gain of 3.1 dBi has been observed at both the resonating frequencies of the T-shaped CPA. The antennas are highly suggested for use in C-band wireless communication applications due to their small size and the results they provide.

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Компактна Т-подібна кругла патч-антена для застосувань у С-діапазоні

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Розроблено та проаналізовано нову дводіапазонну Т-подібну круглу патч-антену (CPA) для застосувань у С-діапазоні. Ця антена може працювати на двох різних резонансних частотах, що робить її придатною для бездротових застосувань у С-діапазоні. Для живлення CPA використовується мікросмужкова лінія передачі з імпедансом 50 Ом. Т-подібна CPA представляє собою процес еволюції, заснований на типовій круглій патч-антені (CPA). Для отримання результатів моделювання, що стосуються діаграм спрямованості, коефіцієнта підсилення, КСХН та коефіцієнта відбиття, з метою перевірки концепції проектування було використано програмне забезпечення An-soft HFSSv13 на основі методу скінченних елементів. Т-подібна CPA розроблена з використанням поліімідної підкладки з $\varepsilon_r = 3{,}5$, висотою 0,1 мм та загальними розмірами лише 38 × 30 мм², що є компактним за розміром порівняно з існуючими круглими патч-антенами. Т-подібна антена CPA працює в потрібних діапазонах ($S_{11} \leq -10$ дБ) 5,2 ГГц та 6,8 ГГц. На обох резонансних частотах Т-подібної антени CPA спостерігається коефіцієнт посилення 3 дБі, що становить 3,1 дБі. Компактна конструкція антен та отримані результати роблять їх дуже рекомендованими для використання в бездротових комунікаційних системах С-діапазону.

Ключові слова: Т-подібна кругла антена, Мікросмужкова патч-антена, Гнучка підкладка, Високоякісний щільний сплав (HFSS), Застосування в С-діапазоні.