CPW-Fed Circular Patch Antenna Design for Sub-6 GHz Applications with an Integrated C-Shaped Slot

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***Abstract*—A compact coplanar waveguide (CPW)-fed circular patch antenna with a single C-shaped slot for wireless communication applications is presented in this study. The projected antenna features a circular radiating patch that includes a centrally embedded C-shaped slot, and it is fed using a symmetric CPW structure with extended ground planes on the same substrate layer. The presence of the C-shaped slot alters the surface current flow across the patch, thereby enhancing impedance matching maintaining a compact and low-profile design. Through proper optimization of the CPW feed dimensions and slot geometry, the antenna achieves stable resonance at 2.94 GHz with a reflection coefficient of -35.85 dB. Due to its simple geometry, single-layer structure, and CPW feeding technique, the proposed antenna is easily fabricated, suitable for sub-6 GHz wireless and WLAN communication systems.**

***Keywords*: CPW-fed antenna, circular patch antenna, C-shaped slot, coplanar antenna, sub-6 GHz.**

I. INTRODUCTION

Miniaturized and effective antennas for use in wireless local area networks (WLAN), Wi-Fi, and other applications in the sub-6 GHz frequency band are now essential due to the quick expansion of contemporary wireless communication systems. In these communication systems, the antenna is required to provide good impedance bandwidth, stable radiation characteristics, compact size, and efficient integration with planar radio frequency (RF) devices. According to recent studies, planar printed antennas are being preferred for these applications because of their lower profile, lower cost of fabrication, and compatibility with printed circuit board (PCB) technology [1, 2]. Among various planar antenna configurations, circular patch antennas have been widely used for different applications due to symmetrical pattern of the radiation. However, the conventional microstrip-fed circular patch antennas generally suffer from confined impedance bandwidth and limited frequency flexibility, which restrict their application in modern compact wireless systems [3]. In order to overcome the drawbacks of conventional circular patch antenna, various techniques like alternative feeding methods, slot loading, and ground-plane modifications have been introduced in recent years. In this aspect, the CPW technique used for feeding the antenna has gained considerable attention owing to its advantages, including single- layer fabrication, wide impedance bandwidth, low radiation loss, and convenient integration with active and passive RF components [4, 5]. Slot loading methods have been used to enhance the performance of the antenna by providing additional current paths within the antenna structure to allow resonance tuning [6]. However, complex slot structures and excessive ground-plane modifications may increase antenna size and design complexity [7 - 9]. Recently, the integration of slots within the antenna patches has been used to improve the impedance parameters without requiring any changes in the overall antenna size. In particular, C-shaped slot loading has shown good promise for efficient optimization of the changes to the surface-current distribution, thereby improving impedance matching and desired resonance characteristics [10, 11]. With suitable optimization of slot dimensions and CPW parameters, good antennas with improved performance can be developed while maintaining fabrication simplicity [12 - 14].

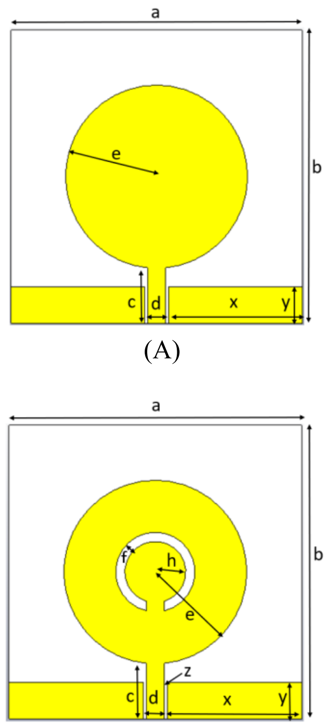
In this study, a compact CPW-fed circular patch antenna with one C-shaped slot embedded in it is proposed for sub-6 GHz wireless communication. The embedded C-shaped slot successfully alters the surface current distribution on the circular patch, hence achieving impedance matching with a compact and minimal configuration. The simple geometry, planar structure, and CPW feeding technique make it suitable for WLAN and sub-6 GHz wireless communication systems.

II. ANTENNA DESIGN

The antenna is realized on an FR-4 lossy substrate with a relative permittivity of 4.4 and a thickness of 1.6 mm. The substrate dimensions of 48 mm × 48 mm were selected to preserve a small design while offering enough space for efficient radiation and suitable impedance matching. The primary radiating structure is a circular patch of copper in the centre of the substrate. The radius of the circular patch is 15 mm, which is optimized to achieve resonance within the sub-6 GHz frequency range. To enhance the performance of the antenna and match the impedance characteristics, a C-shaped slot is introduced inside the circular radiating patch. The C-shaped slot has an inner radius of 5 mm and an outer radius of 6.5 mm. The embedded slot impacts the surface current characteristics by extending its effective electrical current path length. As a result, it affects the resonant characteristics without varying the dimension of the antenna. A CPW technique is used to excite the antenna. In the proposed antenna design, the signal strip and the ground planes are printed on the same side of the substrate. The feed line of the CPW is placed symmetrically with respect to the circular patch of the antenna to maintain its structural symmetry. The feed line is connected directly to the circular patch of the antenna through a connecting strip. Two rectangular ground planes symmetrically placed along both sides of the feed line, forming the CPW structure. The dimensions of the feed line, the dimensions of two ground planes, and the gap between them are carefully optimized to present good impedance matching at the desired frequency. Single-layer fabrication, low radiation loss, and easy integration with planar RF front-end circuits make the use of using a CPW feeding configuration. Overall, compact geometry, single-layer configuration, and an embedded C-shaped slot makes the proposed antenna suitable for sub-6 GHz and WLAN wireless communication applications by keeping simplicity in design and fabrication. The antenna design and dimension are shown in Figure 1 and Table 1 respectively.

III. DESIGN EVOLUTION

The antenna geometry is progressively evolved to investigate the effect of C-shaped slot loading on the impedance characteristics of a CPW-fed circular patch antenna. In the initial configuration, the antenna consists of a single CPW feed exciting a plain circular radiating patch without any C-shaped slot. This basic design represents a conventional CPW-fed circular patch antenna. In this case, the simulated reflection coefficient S11 exhibits a weak resonance with a return loss about -11 dB to -14.4 dB, indicating poor impedance matching. While keeping the same single-port CPW feeding arrangement, a concentric C-shaped slot is added inside the circular patch to improve antenna performance. The insertion of this slot effectively increases the electrical path of the current flow and disrupts the patch's surface current distribution. As a result, the S11 response shows a noticeable improvement, with resonance around 2.94 GHz and a deep return loss of -35.85 dB, indicating good impedance matching. It can be confirmed that the slot-loaded configuration's improved S11 response demonstrates stable impedance matching at the desired operating frequency. The embedded C-shaped slot plays a significant role in tuning the antenna resonance without increasing the overall antenna dimensions. This design evolution highlights that slot embedding within the radiating patch is an effective technique for resonance control and impedance enhancement in CPW-fed planar antennas.



(B)

Figure 1: (A) Geometry of the antenna with one port and no slot, (B) Geometry of the projected antenna with one port and one slot

Table 1: Antenna Specifications

ANTENNA DESIGN SPECIFICATIONS	VALUE (mm)
Substrate length (a)	48
Substrate width (b)	48
CPW feed length (c)	9
CPW feed width (d)	3
Main circular patch radius (e)	15
Inner slot width (f)	1.5
Inner slot inner radius (h)	4.5
CPW ground length (x)	22
CPW ground width (y)	6

Gap between CPW ground and feed line (z)	0.5

IV. RESULT AND DISCUSSION

The performance of the antenna is analyzed by using the CST microwave studio simulation software. In this analysis, the performance of the proposed CPW-fed circular patch antenna is evaluated based on its S11 value to observe the impedance characteristics of both configurations, a simple circular patch without a slot and a circular patch with a C-shaped slot. The purpose of this analysis is to observe the impact of the slot on the resonance behaviour of the circular patch. Without expanding the overall antenna dimensions, the C-shaped slot is incorporated into the circular radiating patch with the goal of improving resonance control and altering the surface current distribution.

Figure 2 demonstrate the simulated reflection coefficient S11 of the two antenna configurations. The antenna resonates at about 6.23 GHz with a return loss of about -14.44 dB in the initial design, which is a basic circular patch without a slot. Performance significantly improves when a C-shaped slot is added to the circular patch. Now the revised design has a deeper return loss of -35.85 dB with a distinct and powerful resonance around 2.94 GHz. This improvement in the S11 parameter shows that the C-shaped slot successfully alters the patch's current flow, increasing its effective electrical length and enhancing impedance matching. Effective power transfer from the CPW feed to the radiating structure is also reflected in the strong resonance at 2.94 GHz. It confirms that adding a C-shaped slot to the circular patch offers better performance and better resonance control than the traditional design.

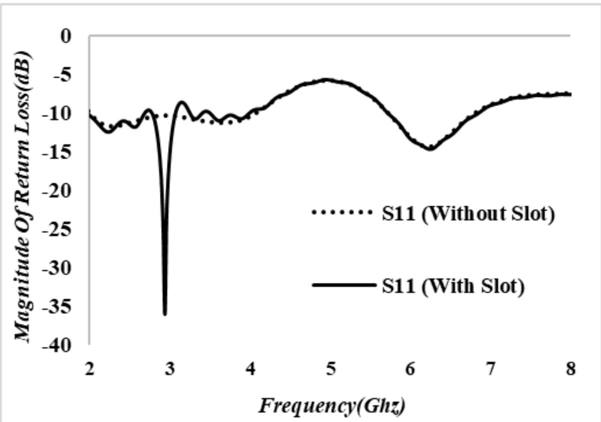


Figure 2: Combined S11 of the two antennas in dB

It is a crucial metric for assessing antenna performance since it shows the direction of emission as well as the efficiency with which input power is transformed into electromagnetic waves. The main lobe of a traditional circular patch antenna without slot is oriented perpendicular to the patch's surface, resulting in a typical broadside radiation pattern. The radiation behaviour clearly alters after the C-shaped slot is inserted into the patch. The electromagnetic field distribution in the far-field region is impacted by the slot's alteration of the current path.

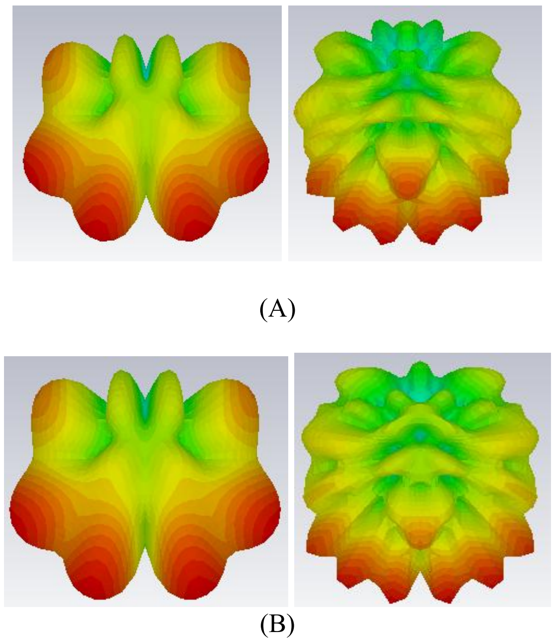
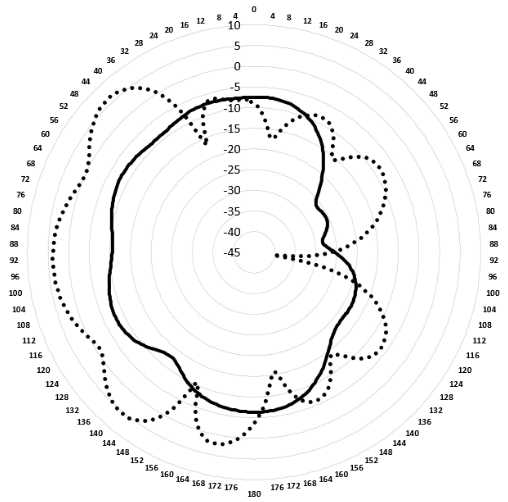


Figure 3: (A) Three-dimensional radiation patterns of antenna without any slot, (B) Three-dimensional radiation patterns of antenna with C-shaped slot.

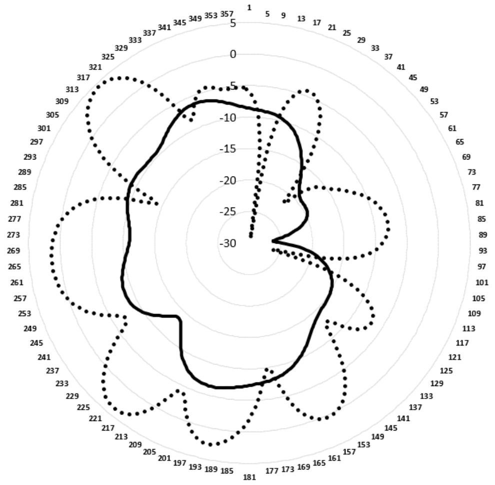
Overall, the above Figure 3 and Figure 4 reveals the impact of the C-shaped slot integration towards the radiation contour while keeping the broadside performance stable.

The surface current distribution analysis provides valuable insight into the operating mechanism of the proposed CPW-fed circular patch antenna shown in Figure 5. It helps in understanding how the electromagnetic energy propagates through the feed ports to the radiating patch and how different antenna elements contribute to radiation at the operating frequencies. Figure. 5 shows the simulated surface current distributions obtained using CST for antenna with no slot and with a slot, respectively. The current density is represented in terms of magnitude (A/m), where regions with higher current concentration indicate dominant radiation contributors.

As the current density gradually decreases near the ground planes, both scenarios exhibit controlled radiation and minimal undesirable surface wave propagation. The obtained current distributions confirm that the C-shaped slot loading and CPW feeding technique's ability to achieve stable radiation performance and effective energy transfer is validated by the observed current distributions.

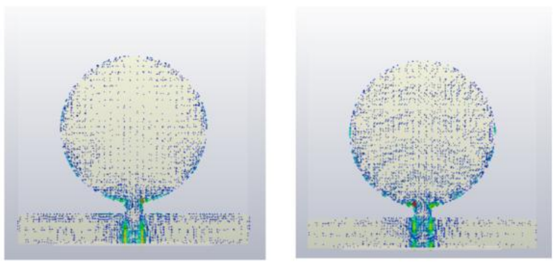


(A)

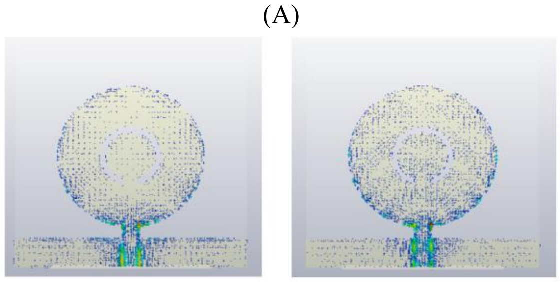


(B)

Figure 4: (A) Two-dimensional radiation patterns of antenna without any slot, (B) Two-dimensional radiation patterns of antenna with C-shaped slot.



(A)



(B)

Figure 5: (A) Surface current distribution of the antenna with no slot, (B) Surface current distribution of the antenna with C-shaped slot.

V. CONCLUSION

A small CPW-fed circular patch antenna has been constructed and tested, both with and without a C-shaped slot. The simple circular patch without the slot exhibits moderate impedance matching performance and resonates around 6.23 GHz. A C-shaped slot is added to the radiating patch to enhance the impedance characteristics and resonance behaviour. With this adjustment, the antenna produces a strong and distinct resonance at about 2.94 GHz, and it also shows good impedance matching with a much improved reflection coefficient of -35.85 dB. The findings show that adding the C-shaped slot successfully changes the surface current distribution, which increases the effective electrical length and improves control over the resonant frequency without changing the antenna's overall size. Both antenna layouts sustain stable broadside radiation, according to radiation pattern analysis. The slot-loaded design shows acceptable side-lobe levels and directional properties. The suggested antenna is easy to construct and can be easily integrated into planar RF systems because of its straightforward design, single-layer CPW feeding, and small size. Overall, the results show that adding a C-shaped slot is a good way to improve the impedance performance.

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