Design and Analysis of a CPW-Fed Dual-Band Antenna for Sub-1 GHz and Sub-6 GHz Applications

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Abstract

This paper presents a newly designed square-shaped multiband antenna optimized for sub 1GHz and sub 6GHz 5G applications. The suggested antenna is specifically designed on a commonly used FR4 substrate material characterized by an effective relative permittivity value (ε_r) of 4.4 and a dielectric loss tangent of 0.02. The total dimensions of the substrate are 110mm in length (Ls), 90mm in width (Ws), and 1.52mm in height (h). The proposed design functions efficiently in two key frequency bands, while the lower operating frequency band broadly spans from 0.91 GHz to 1.41 GHz, and the higher operating frequency band broadly spans from 3.11 GHz to 4.48 GHz. Performance evaluations reveal that the antenna The findings suggest that this antenna can enhance multiband 5G applications, making it a strong contender for next-generation wireless communication systems. The design's multiband functionality and high gain characteristics are particularly advantageous for meeting the diverse requirements of modern 5G networks, ensuring reliable and efficient signal transmission across different frequency ranges.

Keywords. Square Patch, multiband, FR4 substrate, 5G networks, strip

1. INTRODUCTION

As modern communication technologies continue to advance rapidly, there is an increasing need for compact antennas capable of supporting dual- and multi-band operations within a single device across various wireless frequency bands. Microstrip-based dual-band antennas have been extensively explored, particularly for wireless standards such as IEEE WiMAX standard at 3.5 GHz (3.3–3.7 GHz) and wireless WLAN technology at 2.4 GHz (2.4–2.483 GHz) [1]. Numerous antenna structures have been developed to achieve multi-band behaviour, including inverted-F antennas (IFA) [2], designs inspired by metamaterials using split-ring resonators (SRRs) [3], and configurations incorporating defected ground structures (DGS) [4]. Despite their potential, these designs often face drawbacks such as increased physical size, fabrication complexity, and issues related to mutual coupling. To overcome these challenges, asymmetric coplanar strip (ACS)-fed monopole antennas have emerged as compact and efficient alternatives, well-suited for both WLAN and WiMAX applications [5]. While ACS-fed antennas provide dual-band operation with a smaller footprint, their unbalanced feeding structure sometimes results in asymmetrical radiation pattern. Alternatively, the coplanar waveguide (CPW) feeding technique has gained significant interest due to its advantages, such as low profile, reduced surface wave effects, ease of fabrication, and improved impedance matching [6]. Compared to conventional feeding methods like microstrip and coaxial probe feeding, CPW offers enhanced isolation from the feeding network, making it highly suitable for multi-band applications. Multi-band operation in antennas is typically achieved by modifying the radiating patch geometry or introducing slots into the ground plane [7]. While these techniques effectively generate multiple resonances, they often introduce additional fabrication challenges and increased antenna size. Moreover, the use of multiple resonators can result in undesired mutual coupling effects, leading to performance degradation. Consequently, these drawbacks make traditional loading-based multi-band antennas less suitable for space-constrained applications. Fractal geometries have emerged as a promising alternative for designing compact antennas due to their unique space-filling and self-similarity properties [8]. The self-similarity feature enables multi-band operation, while the space-filling nature allows for miniaturization without compromising performance. Various fractal-based antenna designs have been proposed to achieve multi-band functionality while maintaining good radiation characteristics. For instance, a multifractal monopole antenna based on a Koch-like Sierpinski hexagonal carpet structure with coplanar waveguide (CPW) feeding has been proposed, supporting operation at 2.5, 3.5, and 5.5 GHz [9]. Additionally, a novel multiband planar inverted-F antenna (PIFA) with folded edges has been explored for dual-band functionality [10]. Another design features a CPW-fed monopole antenna incorporating a slotted Koch snowflake fractal with a U-shaped slot, tailored for WLAN and WiMAX applications [11]. While these designs demonstrate significant progress in multiband performance, they still encounter limitations such as intricate geometries, fabrication difficulties, and relatively large overall sizes. To effectively address these challenges, this current study presents a CPW-fed compact dual frequency band antenna optimized for wireless communication in both sub-1 GHz and sub-6 GHz frequency ranges. The design uses CPW feeding and an improved radiating structure to provide better impedance bandwidth, omnidirectional radiation patterns, and a compact form, making it suitable for future wireless systems.

2. enhanced proposed cpw antenna design

This section outlines the structural design of the compact dual frequency band antenna and explains the four-step procedure employed during its development. The finalized design layout of the proposed compact antenna is illustrated in Figure 2.1.

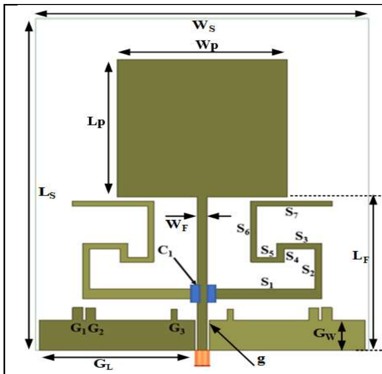


Figure 2.1. Geometry of the Proposed CPW antenna

TABLE 1: GEOMETRIC DESIGN PARAMETERS LIST OF THE PROPOSED CPW ANTENNA (UNIT:mm)

Parameter	Ls	Ws	Lp	Wp
Value	110	90	45.76	45.76
Parameter	Lf	Wf	GL	GW
Value	50.85	2.54	42	10
Parameter	G1	G2	G3	H
Value	4.17x2.7	4x2.6	3.67x1.53	1.52
Parameter	S1	S2	S3	S4
Value	30.64x3.33	13.35x1.8	1.8x10.21	4.71x2.06
Parameter	S5	S6	S7	g
Value	1.65x7.34	18.7x1.65	1.57x22	0.73

The antenna is designed properly to operate over two frequency bands: the first lies within the lower L-band (0.91–1.4 GHz), partially covering sub-1 GHz applications, and the second spans the sub-6 GHz range (3.11–4.48 GHz), making it well-suited for 5G wireless communication systems. The structure is built on an FR4 epoxy substrate material is characterized by a relative effective permittivity value (εr) of 4.4, a dielectric loss factor tangent value (tanδ) of 0.02, and a effective thickness (h) of 1.52 mm,. The substrate simulated dimensions are 110 mm in length and 90 mm in width. The CPW feed transmission line is 2.54mm wide and 60.85mm long, ending with a 50Ω SMA connector for signal transmission. The CPW ground has a length and width of G_L=42mm, G_W=10mm and the ground is modified by the stubs (G_1 to G_3) with different dimensions. The antenna is symmetrically loaded with stubs S1 to S7 to form a dipole with total length (106.98 mm) and maximum width of 3.33 mm.

3. design procedure

Figure 2 illustrates the four structured stages undertaken in the ongoing development process of the newly proposed dual-band antenna, which include:

Stage-1: The approximate dimensions of the antenna are estimated using the following equation:

$$W_p = \frac{c}{2f_r\sqrt{\frac{(\varepsilon_r+1)}{2}}} \quad (1)$$

$$L_p = W_p \quad (2)$$

The dimensions wide of feed line (W_F) with an impedance of 50 ohm were determined by:

$$W_F = \frac{2h}{\pi}\left\{(B-1-\ln(2B-1)) + (\frac{\varepsilon_r-1}{2\varepsilon_r} * \left[\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right])\right\} \quad (3)$$

$$B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_{reff}}} \quad (4)$$

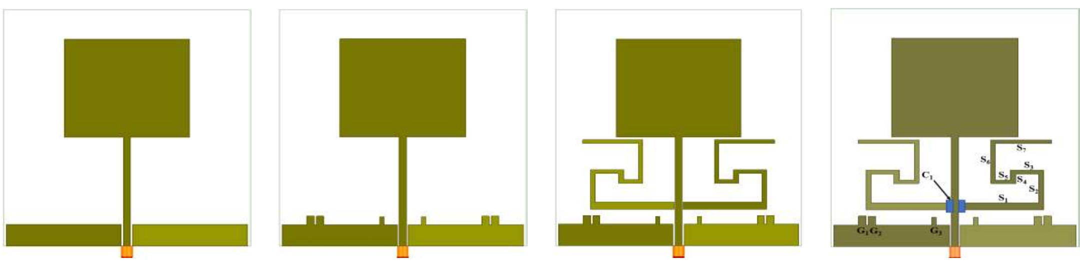
$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + (\frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{W}\right)^{-\frac{1}{2}}) \quad (5)$$

where W_P, L_P, W_F, B, c, h, ε_r, ε_{reff}, f_r represents different aspects of the antenna design. W_P and L_P refer to the width and physical length dimension of the patch, while W_F is the uniform width of the feedline, B is the intermediate values used to calculate the feed line width, and c represents the constant speed of electromagnetic light in free space. The height (thickness) of the substrate is denoted as h, ε_r is the relative permittivity (dielectric constant) of the substrate, ε_{reff} is the approximate effective dielectric constant and f_r is the resonant frequency. The best performance characteristics of the patch antenna is successfully achieved through a comprehensive parametric study using ANSYS HFSS, with optimized dimensions listed in Table.1. Based on the calculations and dimensions, the results from stage 1 are shown in Figure.3.1(a). The figure indicates that the initial antenna design has weak resonance with small dips, leading to poor impedance matching and inefficient radiation. The resonance points are unclear, and high reflection coefficients suggests poor energy transmission and greater signal loss. Additionally, the bandwidth is relatively narrow, limiting the frequency range the antenna can cover.

Stage 2: To enhance the operating bandwidth and reduce signal loss, the stubs G1, G2, and G3 are individually added in the respective ground plane, as shown in Figure.3.1(b). However, the graph indicates that the bandwidth does not improve in the lower frequency range.

Stage 3: The antenna is symmetrically loaded with stubs S1 to S7 and obtained a multiband characteristic, but the bandwidth is not achieved for the desired frequency bands and the graph is shown in Figure.3.1(c).

Stage 4: The final antenna design is added with capacitive loading with resonant dips at 1.3 GHz and 3.5 GHz with reflection coefficients below -20 dB and -30 dB respectively. The overall impedance bandwidth increases, covering a wide frequency range is shown in Figure. 3.1(d). The final design successfully achieves dual band operation, making it suitable for lower L band and sub 6GHz band for 5G and wireless communication.



(a) Stage 1 **(a) Stage 2** **(a) Stage 3** **(a) Stage 4**

Figure 3.1. Different design stages of a Proposed CPW antenna including (a) Stage 1 (b) Stage 2 (b) Stage 3 (c) Stage 4 (Final)

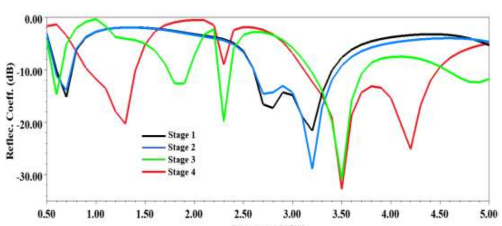


Figure.3.2 HFSS simulated return loss, S11 curves for different stages

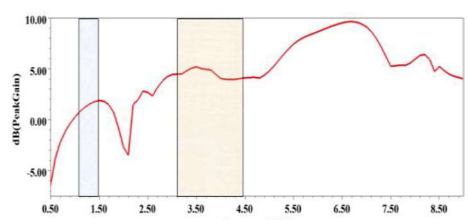


Figure.3.3 Gain vs frequency variation of the proposed CPW-fed dual-band antenna

The overall performance of the proposed CPW-fed dual-band antenna is well illustrated in Figure 3.3. In the lower L-band (0.91–1.4 GHz), the gain varies between -5 dB and approximately 3 dB, ensuring acceptable radiation characteristics for sub-1 GHz applications. In the sub-6 GHz spectrum (3.11–4.48 GHz), the gain ranges from 1.5 dB to 6 dB, making it suitable for 5G and wireless communication systems. The observed gain variations confirm the antenna's capability to provide efficient radiation at the targeted frequency bands. These results demonstrate the antenna's potential for achieving reliable dual-band operation in modern wireless applications.

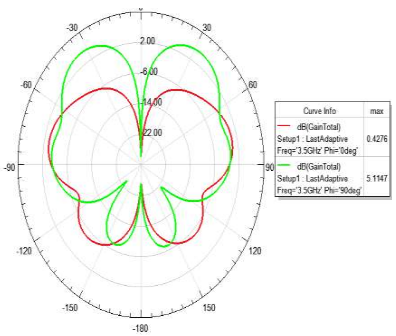


Figure.3.4 Radiation Field Pattern of the Proposed CPW Antenna measured at 3.5 GHz in Phi = 0° and Phi = 90° Planes

Table 2. Performance metrics of the designed antenna is compared with various antennas used in sub-6 GHz 5G systems

Ref.	**Dimension (mm^3)**	**FB (GHz)**	**BW (MHz)**	**Gain (dBi)**	**FBW**
[12]	25x20	3 - 3.9, 4.3 - 5	900, 700	1.98, 1.98	25.35%, 14.67%
[13]	30x29x9	2.38 - 2.77	390	1.42	16.25%
[14]	40x40x1.124	2.36 - 2.74, 5.14 - 6.18	410, 1040	0.74, 2.3	15.57%, 18.9%
[15]	136x68x1	3.4 - 3.6	400	-	11.11%
[16]	30x34x0.8	1.9 - 2.17, 3.4 - 3.6, 5.15 - 5.35	270, 200, 200	-1, 1, 3.5	13.5%, 5.71%, 4%
This work	**110x90x1.52**	**0.91 - 1.4, 3.11 - 4.48**	**490, 1370**	**0.42, 5.11**	**42.42, 36.1%**

FB: Frequency Band, BW: Bandwidth, FBW: Fractional Bandwidth

The proposed CPW-fed antenna exhibits an omnidirectional radiation pattern with stable gain characteristics at both operational bands. Figure 3.4 presents the radiation patterns at 3.5 GHz, showcasing the broad coverage, which makes it well suited for sub-6 GHz wireless applications. Table 2 presents a comparative analysis, highlighting the compact dimensions, wider bandwidth, and superior fractional bandwidth of the proposed antenna when compared to existing designs. The antenna consistently delivers a gain of 5.11 dBi in the higher frequency band and 0.42 dBi in the lower band, thereby confirming its effectiveness in dual-band operation. These results confirm the effectiveness of the proposed design in achieving compactness, wide bandwidth, and adequate gain.

4. conclusion

The CPW-fed dual-band antenna presented in this study effectively covers sub-1 GHz and sub-6 GHz frequency ranges, offering enhanced bandwidth and stable gain. Compared to previous works, the proposed design offers a superior performance in fractional bandwidth of 42.42% (lower band) and 36.1% (higher band), ensuring better frequency coverage. The compact dimensions and stable radiation characteristics make it a strong candidate for modern wireless applications.

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