DUAL-BAND PLANAR INVERTED-F ANTENNA DESIGN FOR CUBESAT X AND KU-BAND APPLICATIONS

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***Abstract* – Compact Planar Inverted-F Antenna (PIFA) is developed for multiband satellite communication applications, specifically targeting CubeSat platforms. Designed to operate across both the X-band and Ku-band, the antenna demonstrates wide impedance bandwidths with S_{11} below –10.45 dB in the 9.00–11.58 GHz range and below –10.94 dB in the 12.88–13.22 GHz range. The antenna is implemented on a low-cost FR4 substrate with dimensions of 29 mm × 36 mm × 1.6 mm, making it suitable for space-constrained satellite environments. The design is optimized in free space using CST Studio Suite based on the Finite Integration Technique (FIT) to ensure performance consistency under actual satellite operating conditions.**

The antenna achieves a peak gain of 7.2 dBi and a radiation efficiency ranging from 50% to 77% across the operating bands. The multiband functionality enables flexible communication across multiple satellite links, such as telemetry, tracking, and data downlink/uplink, potentially reducing the need for multiple antenna systems and minimizing payload complexity. These characteristics make the proposed antenna a strong candidate for integration into modern CubeSat and small satellite platforms that demand compact, efficient, and broadband RF solutions

I. INTRODUCTION

Cube Satellites, or CubeSats, revolutionize satellite technology with 10-centimeter (1U) sides. They are cost effective and very practical for student’s projects. They attracted aerospace companies, researchers, institutes, and governments worldwide due to their small size and standard form factors (1U, 2U, 3U, etc.) [1].

CubeSats can communicate with each other and form a swarm to monitor and sense enormous areas. CubeSats need broadband, compact, high-gain antennas to communicate with each other and the ground station.

However, CubeSats' limiting size and weight create major antenna design problems. Optimizing radiation performance requires compact, lightweight antennas with high gain and wide bandwidth [1,3].

Because of its favorable qualities, including ease of integration, lightweight, conformability, low cost, and ease of design, the Planar Inverted-F Antenna (PIFA) is widely used for mobile communication [4,5]. For lower-frequency applications including ISM band, GPS, S-Band WiMAX, LTE, and Wi-Fi, multiband PIFA has frequently suggested designs [6–9]. The X-band (9–12 GHz) and Ku-band (12–18 GHz) are also suggested for high-frequency applications including radar and satellite communication systems [10–13]. Novel approaches have been put forth in the literature to improve bandwidth (BW), isolation (Multiple Input Multiple Output (MIMO)), size reduction, and radiation performance in order to achieve the necessary performance for PIFA in certain applications.

For Low Earth Orbit (LEO) satellite telemetry connection with ground stations, the work in [14] developed a dual-band (135 and 435 MHz) PIFA for transmission and receiving. A 5:1 scaled prototype of the satellite body was built on a metallic cube after the authors simulated and optimized the antenna's performance using CST. It is proved that the proposed PIFA outperformed conventional monopole antennas in gain, radiation patterns, and compactness and robustness, making it ideal for LEO spacecraft where space and weight are crucial. The work in [15] designed and analysed a 4× 1 MIMO PIFA array at 10 GHz for X-band applications such satellite communication, radar, and medical systems. Using CST, the proposed antenna achieved a bandwidth of 240 MHz, an HPBW of 64.4°, a gain of 12.87 dB, directivity of 13.24 dBi, and efficiency of 91.9%.

A compact slotted PIFA with a Reactive Impedance Surface (RIS) for multiband (2.4, 4.2, 7.1, and 9 GHz) WiMAX, C-band satellite uplink and downlink, and X-band wireless applications [16]. The bandwidth, gain, and efficiency are improved using the FR4 substrate with numerous dielectric layers while making the antenna low-profile and compact. The multiband impedance matching operation is enabled by rectangular radiating patch slots enable multiband operation. A simple, cost-effective, and highly efficient dual-band 20/30 GHz PIFA element for satellite reconfigurable reflectarray (RRA) applications was proposed in [17]. By establishing dual-band RRAs, it advances MIMO, 5G/6G, wireless networks, and satellite systems. It offered linear polarization with excellent purity (–20 dB), low transmission losses (0.15 dB), great signal integrity, and low energy loss.

A multi-state tunable X-band PIFA made with meandering lines and a metallic back cavity demonstrates the PIFAs' reconfigurability, which allows for flexible control over resonant frequencies—a crucial characteristic in dynamic contexts [13].

Multiple bands for lower-frequency applications including ISM band, GPS, S-Band WiMAX, LTE, and Wi-Fi, PIFA has frequently suggested solutions [6–9]. Additionally, it is suggested for high-frequency uses such satellite communication systems and radar in the X-band (9–12 GHz) and Ku-band (12–18 GHz). The literature proposes novel methods to increase bandwidth, isolation (MIMO), size reduction, SAR reduction, and radiation performance for PIFA in particular applications.

A driven monopole and metal case were used in [18] to optimize an inexpensive, straightforward X-band (10.5 GHz) inverted-F antenna (IFA) for active RFID tags. A compact quad-band PIFA operating in WiMAX (3.5 GHz), WLAN (5.2 GHz), X-band (7.25–7.75 GHz), and ITU (8.02–8.4 GHz) frequencies was proposed by Ojaroudi et al. (2014). This design allows for multiband operation that encompasses satellite frequencies by incorporating a hook-shaped slot and specially designed slots in the ground plane [6].

MIMO arrangements are excellent for improving data throughput, spectral efficiency, and link stability without adding spectrum or transmit power [19]. The proposed 4×1 MIMO X-band (10.16 GHz) PIFA array [20] boasts high gain (12.87 dBi), impedance matching, and efficiency (91.9%), making it suited for satellite and radar systems. A genetic algorithm-based approach is utilized to create a dual-band (2.52–3.71 GHz and 5.2–5.95 GHz) MIMO PIFA with strong isolation and outstanding MIMO metrics [21], making it appropriate for high-performance wireless systems. Many studies have tackled the wide and numerous frequency band problem. The octa-band (DCS 1800, UMTS, PCS, Wi-Bro, WiMAX, Wi-Fi (5 GHz), and WLAN (5.39–5.47 GHz and 7.03–7.93 GHz) PIFA [8] used meandered lines and ground slots for various wireless phones. Iyampalam and Ganesan (2019) suggested a compact triple-band (0.795 GHz, 2.050 GHz, and 3.405 GHz) IFA for LTE portable devices with efficient impedance matching [7]. A penta-band IFA with spiral-shaped resonators was developed in [9] for GPS, S-Band, Wi-MAX, 5G, and WLAN applications with independent tunability and strong downsizing. Additionally, compactness strategies were researched to circumvent portable device physical limits.

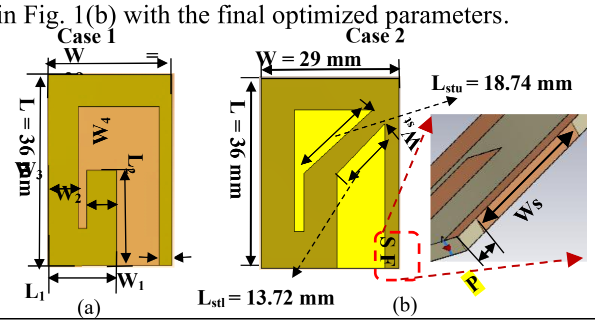
In [22], Minkowski pre-fractal geometry and defective ground plane are employed to minimize ISM band antenna size (2.19–2.52 GHz) without affecting performance, achieving consistent radiation pattern and boresight gain. In [10], a short-circuit wall at the electric field null increased the compactness and bandwidth of L-shaped feedline X-band (8.34–10.09 GHz) microstrip patch PIFA antenna by 50% and 18.9%, respectively.

In this work, a compact Planar Inverted-F Antenna (PIFA) is designed for CubeSat multiband satellite communication. It is designed for both X-band (9.00-11.58 GHz) and Ku-band (12.88-13.22 GHz) and, constructed on a low-cost FR4 substrate (ε_r= 4.3, tan δ ≈ 0.025, and a thickness of 1.6 mm) of 29 mm× 36 mm, is ideal for space-constrained satellite applications. The Finite Integration Technique (FIT)-based CST Studio Suite is used for simulation and optimization, where detailed parametric studies are included.

Alongside this section, Section II provides comprehensive parametric studies to address the design evolution of the proposed PIFA. The results are shown in Section III, and the work's conclusion is given in Section IV.

II. Design and Analysis

Figure 1(a) shows the conventional layout (Case 1) of the dual PIFA antenna with width (W= 29 mm) and length (L= 36 mm). It should be noted that, a 50% size reduction of PIFA is obtained when the patch is shortened to the ground via a shorting pin or sheet (width, Ws) at the position, S, with a distance, P, from the feeding point, F, and this allows a quarter wavelength resonance [24]. Case 1 achieves S_{11} < -10.94 dB at (9–10.46 GHz). However, the proposed dual band PIFA (Case 2) is obtained by adding stub with width (W_{st}), upper length (L_{stu}), and lower length (L_{stl}) as depicted in Fig. 1(b) where the required dual band (S_{11} <–10.45 dB at 9.00-11.58 GHz and S_{11} <–10.94 dB at 12.88-13.22 GHz) are achieved as illustrated in Fig. 1(c). The final layout of the proposed antenna is shown in Fig. 1(b) with the final optimized parameters.



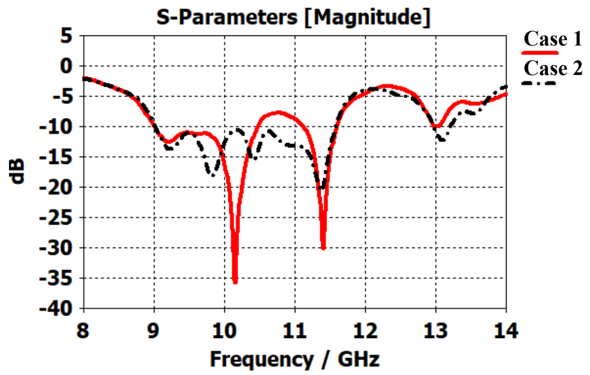
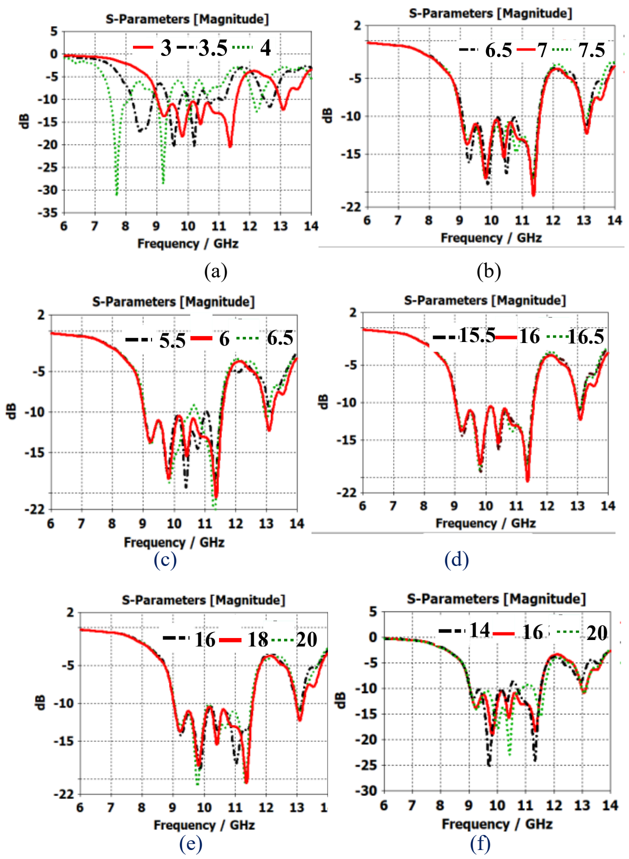


Fig.1. Design modification: (a) Case 1, (b) Case 2, and (c) simulated S_{11}, and (e) the equivalent circuit of the proposed dual band PIFA

The optimized parameters are obtained using detailed parametric studies shown in Fig. 2 in terms of S_{11}, where the optimized value is shown with a solid red line. The optimized design parameters that enable the proposed antenna to achieve S_{11} <–10.45 dB at 9.00-11.58 GHz and S_{11} <–10.94 dB at 12.88-13.22 GHz as follows: W= 24 mm, L = 36 mm, L_1= 16 mm, L_2 = 29 mm, W_{st}= 2.9 mm, L_{stl} = 6 mm, L_{stu} = 10.43 mm, W_1 = 3 mm, W_2 = W_3 = 7 mm, W_4 = 6 mm, P =2.4 mm, F = 3 mm and W_S= 16 mm.



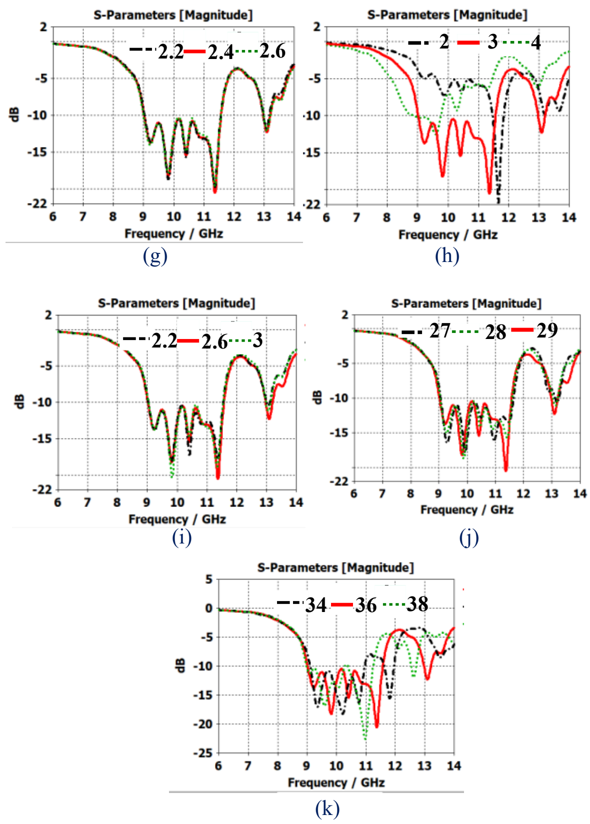
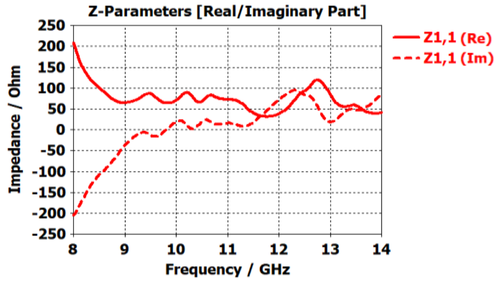


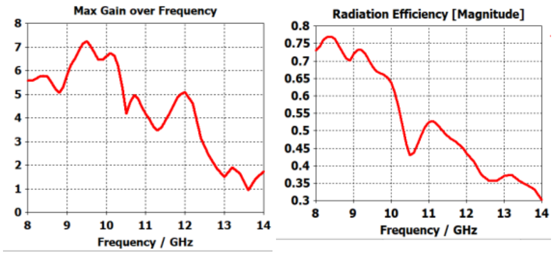
Fig.2. (Dimension in mm): Parametric study on (a) W_1, (b) W_2= W_3, (c) W_4, (d) L_1, (e) L_2, (f) W_s, (g) P, (h) F, (i) W_{st}, (j) L, and (k) W

III. Results and Discussion

As explained in the previous section, in Fig. 1(c), the proposed PIFA provides good matching across the dual band across S_{11} <–10.45 dB at 9.00-11.58 GHz and S_{11} <–10.94 dB at 12.88-13.22 GHz which can be explained by input impedance where the real and imaginary components oscillate around 50 Ω and 0 Ω, respectively. As shown in Fig. 3(b), the simulated realized gain reaching 7.2 dBi and 1.8 dBi at the first and second band, respectively. The simulated radiation efficiency as shown in Fig. 3(c) ranges from 48% to 77% in the first band and 35% to 38% in the second band and this owing to the use of the lossy substrate FR4. The 2D radiation patterns of the proposed antenna at 9 GHz, 10 GHz, 11 GHz and 13 GHz are shown in Fig. 4(a), 4(b), 4(c) and 4(d), respectively. The antenna provides stable broadside patterns which in turns ensures reliable communication links for CubeSat applications, maintaining efficient transmission toward the ground station despite satellite attitude variations

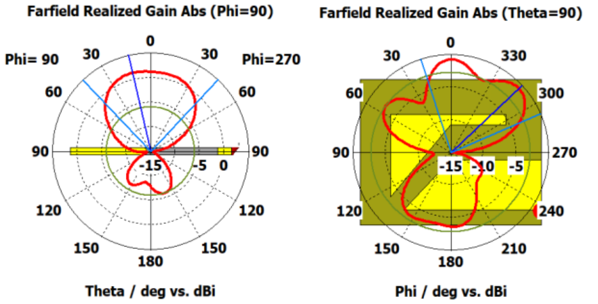


(a)

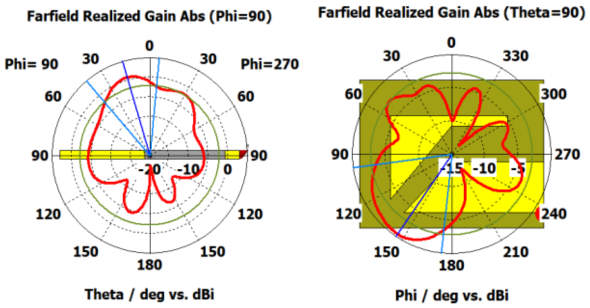


(b) (c)

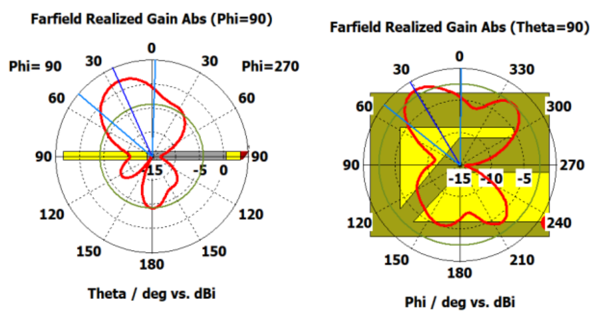
Fig. 3. The simulated (a) input impedance, (b) maximum realized gain and (c) radiation efficiency of the proposed dual band PIFA.



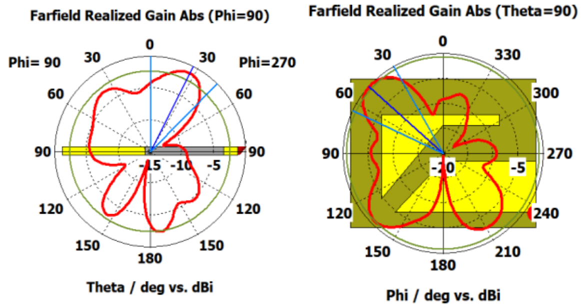
(a)



(b)



(c)



(d)

Fig. 4. The simulated 2D radiation patterns of the proposed dual band PIFA at (a) 9 GHz, (b) 10 GHz, (c) 11 GHz, and (d) 13 GHz.

IV. Conclusions

The compact multiband Planar Inverted-F Antenna (PIFA) has great potential for CubeSat and small satellite communication systems. The antenna works efficiently over the X- and Ku-bands with wide impedance bandwidths, 7.2 dBi peak gain, and up to 75% radiation efficiency. Integration onto space-limited platforms is possible due to its compact FR4 construction and free space optimization. The antenna supports telemetry, tracking, and data transfer, reducing the need for several devices and making next-generation CubeSat missions lightweight and cost-effective. Integrating reconfigurable or tunable elements to enable dynamic frequency switching, analyzing the antenna's performance in real space, exploring array configurations for higher gain and beam steering, and investigating low-loss or flexible substrates to improve efficiency and adaptability are future goals. On-orbit testing or CubeSat prototype deployment will also be done to verify its practicality and dependability.

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