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RESEARCH ARTICLE

Partial Ground-Based Miniaturized Ultra Wideband Microstrip Patch Antenna

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Abstract

Objective: To implement a miniaturized ultra-wideband microstrip patch antenna for wireless applications. **Methods:** The antenna design is established on the FR-4 substrate with a relative permittivity of 4.4 and a thickness of 1.60 mm. The entire area of the projected antenna is 26.33 x 19.39 x 1.60 mm^3, and it is simulated in the CST MWS tool. An inset-fed patch and a modified ground plane are utilized to construct the antenna. **Findings:** The antenna's working frequency range is from 3.780 to 10.460 GHz with a peak gain of 4.8 dBi. The parameters such as VSWR, radiation patterns, return loss, and gain of the antenna are presented in this letter. **Novelty:** Designing an inset-fed patch antenna with a wide bandwidth is a challenge. Novelty can come from achieving a wider bandwidth than previously reported by optimizing the feed point location. The majority of the designed ultra-wideband antenna structures are complex with large sizes, but the existing antenna structure is implemented using an inset-fed patch and partial ground method. The fabricated antenna satisfies the desirable ultra-wideband performance in the 3.1–10.6 GHz frequency band. The antenna can be utilized for X-band, C-band, RFID, upper S-band, and satellite communication applications.

Keywords: Ultrawideband; Microstrip antenna; Partial ground plane; inset fed patch; Return loss; Radiation Patterns; Gain; VSWR

1 Introduction

In contemporary wireless communication systems, patch antennas have found widespread application due to their exceptional polarization characteristics and seamless integration with microwave integrated circuits. Within these systems, the microstrip antenna serves a dual purpose, functioning not only as a radiator but also as a resonator for power amplifiers within the active circuitry. Nonetheless, without meticulous design considerations to mitigate harmonic resonance and spurious emissions, this antenna has the potential to generate undesirable electromagnetic radiation, thereby impacting the overall performance of these systems [1]. Ultra Wide-

Band (UWB) communication has gathered substantial attention due to its ability to operate over a varied range of frequencies while maintaining good performance. Among researchers, planar slot antennas have become widely utilized due to their numerous advantages, such as their compact size, low development cost, and simple structure. As a result of these appealing characteristics, planar slot antennas have gained popularity in UWB antenna design, and current research efforts have been focused on them [2,3]. In 2002, the Federal Communication Commission (FCC) officially designated and allocated the frequency range of 3.1 GHz to 10.6 GHz for Ultra Wide Band Communications. UWB possesses characteristics such as low power consumption, a broad frequency range, minimal proximity effects on human organs, and limited interference with other wireless devices, rendering it well-suited for applications within WBANs [3].

The advantage of UWB systems is their low-power consumption, a requirement for wireless equipment in communication systems to reduce the dangerous effects of their RF radiation on the human body. Other advantages include high immunity due to the low output power required for military applications, resistance to interference (which means that if noise exists in some frequency bandwidth, it disappears in another portion of the bandwidth), high performance in multipath channels, and high penetration capability [4]. In [5], an innovative microstrip patch antenna with triple-band capabilities catering to WiMAX/LWLAN/UWLAN and downlink C-band satellite reception applications is designed. The design enhances Ultra-Wideband (UWB) functionality by incorporating strategically positioned strips on a wideband printed open space antenna, effectively eliminating the limitations of single and dual-band operation. However, the antenna size is large, and the gain is also less. In [6], the antenna configuration comprises a circular-shaped modified patch and is paired with a finite semicircular ground plane. Achieving Ultra-Wideband (UWB) performance is accomplished through the addition of a staircase-shaped slot in the radiating element and a rectangular slot in the ground plane, but the antenna size is large. Fang and colleagues pioneered the development of a graphene-assembled film (GAF)-based ultra-wide bandwidth (UWB) antenna with a compact and low-profile design, explicitly implemented for wearable applications within the frequency range of 4.1 to 8.0 GHz [7]. In a similar vein, Natale and Giampaolo introduced a reconfigurable UWB antenna tailored for WBAN on fabric materials [8]. Meanwhile, Zhang and his team put forth an innovative flexible UWB antenna capable of covering an extensive frequency range from 3.06 to 13.58 GHz, maintaining its functionality in both flat and bent states [9]. Additionally, El Gharbi and associates developed a UWB antenna that functions efficiently from 3.1 GHz to 11.3 GHz, with its substrate composed of felt textile material [10].

In pursuit of enhancing the performance characteristics of UWB antennas, this article delves into the exploration of a rectangular-shaped UWB antenna on an FR-4 substrate. The UWB antenna has been meticulously engineered to function optimally within the frequency bands of 3.04–10.70 GHz. To evaluate the efficacy of this antenna design, a physical prototype was fabricated and subjected to measurements of its reflection coefficient, with comparisons drawn against simulated results. Furthermore, this article delves into the examination of various antenna parameters, including gain, radiation pattern, and radiation efficiency, all of which were simulated utilizing CST MWS simulation software and are thoroughly discussed within the publication.

2 Methodology

The basic inset-fed patch antenna at 7.0 GHz is designed on FR-4 substrate material as depicted in Figure 1 and dimensions for the antenna design presented in Table 1.

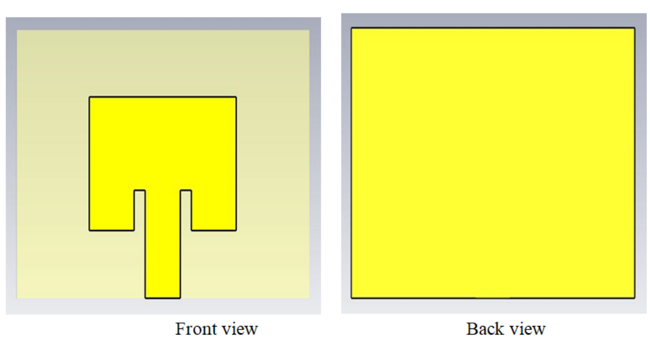


Fig 1. The basic inset-fed patch antenna

Table 1. Geometric parameters of the antenna

	Basic Antenna Ground Plane and Patch Dimensions	Partial ground plane implementation Dimensions
Ground Plane Width Wg	26.33	26.33
Ground Plane Length Lg	19.39	4.99
Patch Width Wp	9.70	9.70
Patch Length Lp	13.16	13.16

For the design and construction of the antenna, the following formulas were utilized[7]: Patch width and its length are calculated by Equations (1) and (2).

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

Where c=3x10^8 m/s, f_r = Resonating frequency and ε_r= dielectric constant.

$$L = L\,eff - 2\Delta L \tag{2}$$

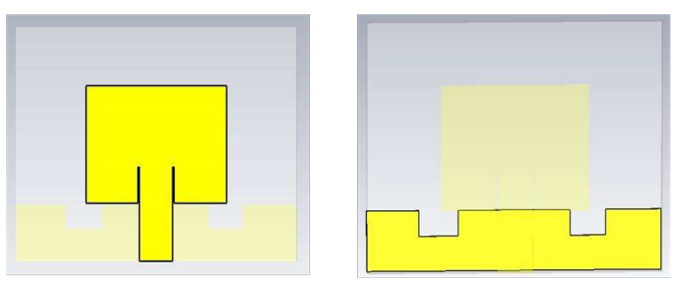
Where

$$\Delta L = 0.412h\left[\frac{(\varepsilon cef + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon lof - 0.258)\left(\frac{W}{h} + 0.8\right)}\right] \tag{3}$$

$$eff = \left(\frac{\varepsilon' + 1}{2}\right) + \left(\frac{\varepsilon' - 1}{2}\right)\left[1 + 12\left(\frac{h}{W}\right)\right]^{-0.5} \tag{4}$$

$$L_{eff} = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_{reff}}} \tag{5}$$

The patch as well as ground planes are modified to construct the ultra-wide band antenna as depicted in Figure 2.



(a) Front view (b) Structure of ground plane

Fig 2. Proposed antenna structure

3 Results and Discussion

The ultra-wideband capability is achieved by modifying the ground structure and the patch. The proposed antenna radiates at 8.388 GHz with an S11 of -42.91 dB and a bandwidth of 6.673 GHz. The simulated and measured return loss, -10dB bandwidth of the projected antenna, is presented in Figures 3 and 4, respectively.

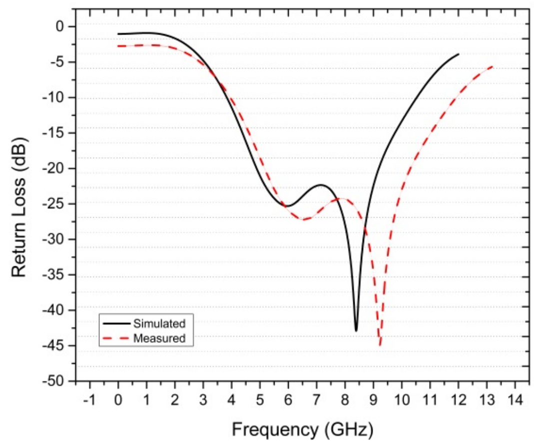


Fig 3. The S_{11} v/s frequency graph

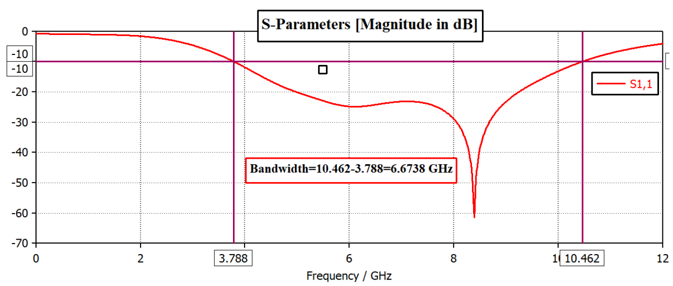


Fig 4. Proposed antenna operational bandwidth

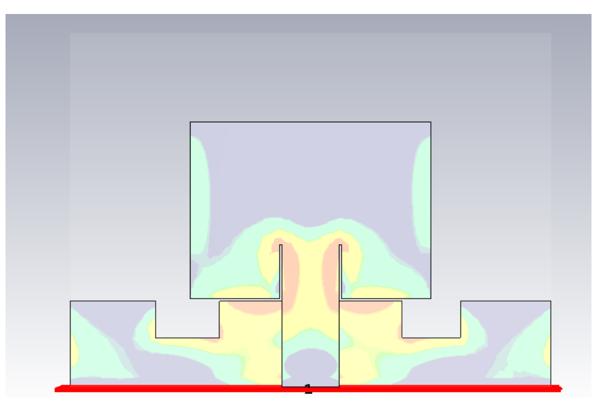


Fig 5. Resultant antenna surface current distribution

The VSWR value from 3.78 GHz to 10.462 GHz is less than or equal to 2, indicating low reflections within this frequency range. The surface current distribution of the projected antenna is depicted in Figure 5, indicating that the maximum current is concentrated at the feed line.

Figure 6 represents the gain vs. frequency (simulated and measured) graph of the proposed antenna. The gain of the antenna varies from 1 to 4.8 dBi. The simulated and measured radiation patterns are depicted in Figure 7. The E-plane represents an omnidirectional pattern, and the H-plane also indicates an omnidirectional pattern but with null and a few side lobes. The fabricated antenna is depicted in Figure 8.

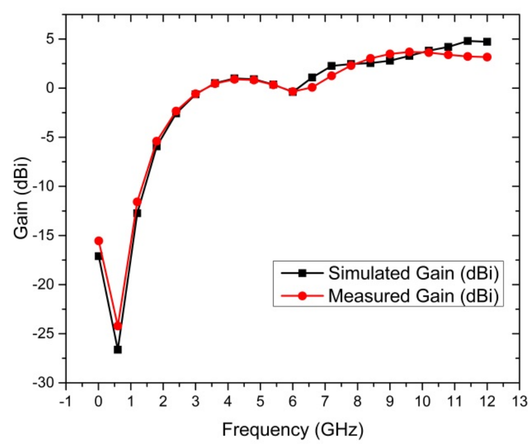


Fig 6. Proposed antenna gain v/s frequency characteristics

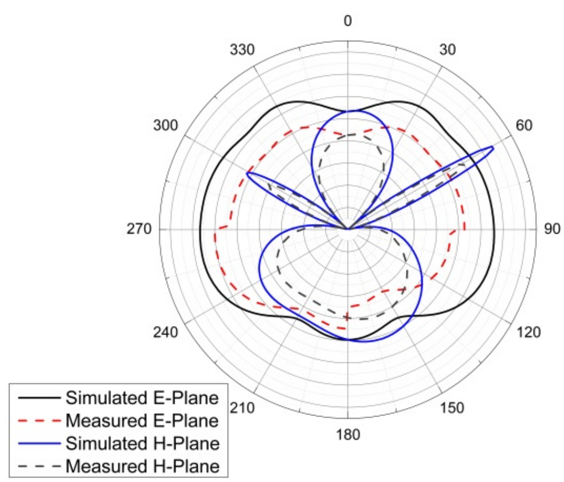


Fig 7. Radiation patterns of proposed antenna

Designing an inset-fed patch antenna with wide bandwidth is a challenge. Novelty can arise from achieving a broader bandwidth than previously reported by optimizing the feed point location. The majority of the designed ultra-wideband antenna structures are complex and large, but the existing antenna structure is implemented using an inset-fed patch and partial ground method. In summary of the proposed work, various antenna models and their results are presented in Table 2.

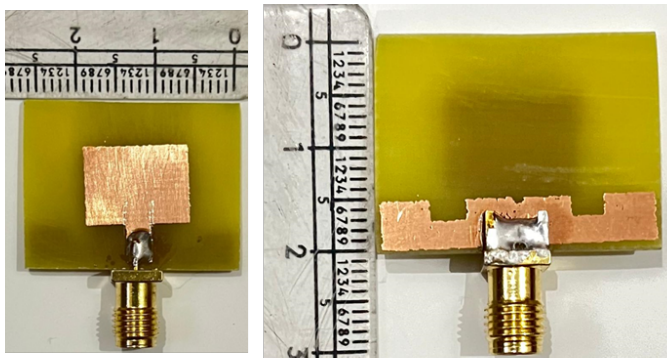


Fig 8. Fabricated antenna

Table 2. Performance comparison

Reference	Operating Bandwidth (GHz)	Material Used	Antenna Size(WxL) mm^2	Peak Gain (dBi)
(9)	2.85–19.4	Kapton polyimide (3.5)	38 × 30.4	4.5
(11)	3.10–10.6	Rogers RO4232 (3.2)	75 × 63	3.5
(12)	3.30–12.0	Composite laminate (2.70)	40 × 40.5	4.90
(13)	3.04–10.70 and 15.18–18	PET (3.2)	47 ×25	4.25
Proposed Antenna	**3.78-10.46**	**FR-4 (4.3)**	**26.33X 19.39**	**4.8**

4 Conclusion

The design and implementation of the projected antenna are simple and compact. The majority of the designed ultra-wideband antenna structures are complex and large, but the existing antenna structure is implemented using an inset-fed patch and partial ground method. The antenna radiates from 3.788 GHz to 10.462 GHz with a peak gain of 4.8 dBi. The antenna design is based on the FR-4 substrate with a relative permittivity of 4.4 and a thickness of 1.60 mm. The overall antenna size is 26.33 x 19.39 x 1.60 mm^3. The fabricated antenna satisfies the desirable ultra-wideband performance in the 3.1–10.6 GHz frequency band. The antenna can be utilized for X-band, C-band, RFID, upper S-band, and satellite communication applications.

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