A Novel Triple U-Slot Microstrip Patch Antenna Design for Multiband Applications

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Abstract— **This paper presents a novel triple U-slot microstrip patch antenna specifically designed for multiband wireless communication applications. By incorporating three U-shaped slots strategically positioned within the radiating patch, the proposed design achieves multiple resonant frequencies, thereby enabling operation across several communication bands while maintaining a compact and low-profile structure. The slot geometry and placement are optimized to enhance impedance matching and bandwidth performance without compromising radiation efficiency. Simulated and analyzed parameters such as return loss, gain, bandwidth, and radiation pattern demonstrate that the antenna can effectively cover a wide range of applications including WLAN, WiMAX, and sub-6 GHz 5G systems. The proposed design offers a practical and efficient solution for future wireless technologies requiring compact multiband antennas.**

Keywords—Antenna, U-slot, Microstrip, Multiband, C-badn, X-band, Patch.

I. INTRODUCTION

With the ever-expanding scope of wireless communication systems, the demand for antennas capable of operating efficiently over multiple frequency bands has become increasingly critical. The evolution of mobile networks, wireless data services, Internet of Things (IoT) devices, and emerging technologies such as 5G and beyond has intensified the need for compact, high-performance, multiband antennas that can be seamlessly integrated into portable and embedded devices. Conventional antenna designs often face limitations in meeting these multiband requirements without introducing additional complexity or increasing the overall size of the device.

Microstrip patch antennas (MPAs), due to their low-profile structure, lightweight nature, ease of fabrication, and compatibility with printed circuit board (PCB) technology, have emerged as a preferred choice for many wireless systems. However, a major drawback of traditional microstrip patch antennas lies in their inherently narrow bandwidth and single-frequency operation. This has prompted extensive research efforts aimed at modifying and enhancing MPA structures to support multiband and broadband performance.

One effective technique for achieving multiband behavior is the incorporation of slots within the radiating patch. Slotting alters the surface current distribution and introduces additional current paths, which in turn generate multiple resonant modes. Among the various slot geometries explored, the U-slot configuration has gained considerable attention due to its ability to facilitate dual or multiband operation while preserving the antenna's compact form factor and radiation efficiency. The U-slot technique enhances impedance bandwidth by providing capacitive and inductive coupling effects, making it suitable for a variety of high-frequency applications.

Building upon this concept, the present work proposes a novel triple U-slot microstrip patch antenna design, wherein three U-shaped slots are strategically embedded into the rectangular radiating patch. The objective of this approach is to enable the antenna to resonate at three or more distinct frequency bands, making it suitable for modern multiband communication standards such as WLAN (2.4/5.8

GHz), WiMAX (3.5 GHz), LTE, and sub-6 GHz 5G. The proposed configuration introduces additional degrees of freedom in tuning resonant frequencies through slot length, width, and position adjustments, without the need for increasing the overall antenna size or adding complex structures.

The proposed antenna design also focuses on achieving improved return loss, wide bandwidth, stable radiation patterns, and sufficient gain at each operating band. Parameters such as substrate material, dielectric constant, feed mechanism, and ground plane modifications are considered in the design process to optimize performance. Additionally, the mutual coupling effects between slots are analyzed to ensure minimal interference and enhanced multiband separation.

Several recent studies have explored single and dual U-slot antennas; however, the introduction of a triple U-slot arrangement offers more flexibility and application coverage while maintaining simplicity and ease of manufacturing. The present design aims to fill the research gap by proposing an optimized structure that not only delivers multiband behavior but also satisfies the performance requirements of emerging wireless systems.

This paper provides a comprehensive account of the proposed triple U-slot antenna design, including its structural configuration, simulation setup, parametric analysis, and performance evaluation. Through comparative analysis with existing designs, the novelty and advantages of the proposed antenna are clearly demonstrated. This work contributes to the ongoing development of compact and efficient multiband antenna systems suitable for next-generation communication platforms.

II. METHODOLOGY

The proposed designing of U-slot microstrip patch antenna is as following-

1. **Define Design Specifications:** Specify the desired operating frequency or frequencies for the U-Slot Microstrip Patch Antenna. Determine the substrate material properties, substrate height (h), and dielectric constant (ε_r). Establish the desired dimensions of the patch, such as length (L) and width (W), based on the target frequency.

2. **Microstrip Patch Dimensions:** Use empirical equations or design charts to estimate the initial dimensions of the microstrip patch. For a rectangular patch, the resonant frequency (f_0) can be estimated using the following empirical equation:

$$f_0 = \frac{c}{2\sqrt{\varepsilon_{\mathrm{eff}}}} \times \sqrt{\frac{1}{L^2 - W^2}}$$

where:

- c is the speed of light,
- $\varepsilon_{\mathrm{eff}}$ is the effective dielectric constant.

3. **U-Slot Introduction:** Determine the location and dimensions of the U-slot on the microstrip patch. The U-slot introduces additional capacitance and inductance, affecting the resonant frequency. The effective length (L_{eff}) of the microstrip patch with the U-slot can be expressed as:

$$L_{\mathrm{eff}} = L + \Delta L$$

where:

- ΔL is the additional effective length introduced by the U-slot.

4. **Resonant Frequency Adjustment:** Adjust the dimensions of the U-slot to achieve the desired resonant frequency. The change in resonant frequency (Δf) due to the U-slot can be estimated using:

$$\Delta f = \frac{1}{2\pi\sqrt{L_{\mathrm{eff}} C_{\mathrm{eff}}}}$$

where:

- C_{eff} is the effective capacitance introduced by the U-slot.

5. **U-Slot Geometry Optimization:** Perform iterative simulations or calculations to optimize the U-slot dimensions for the desired resonant frequency. Consider the impact of the slot length, width, and position on the overall performance of the antenna.

6. **Antenna Feed Mechanism:** Choose an appropriate feeding mechanism for the microstrip patch antenna, such as microstrip line feeding or coaxial probe feeding. Optimize the feed location and dimensions to achieve good impedance matching.

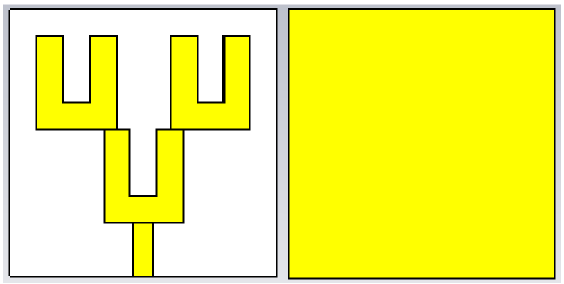
7. **Simulation and Analysis:** Utilize CST electromagnetic simulation tools to model the U-Slot Microstrip Patch Antenna with the optimized dimensions. Analyze the simulation results for resonant frequency, return loss, radiation pattern, and other relevant parameters.

III. SIMULATION RESULTS

Simulation is performed using the CST software- The resonant frequencies of 9.3 GHz for Band-I and 11.65 GHz for Band-II align closely with the design specifications, underscoring the accuracy of the optimization process.

Table 1: Antenna design parameters

Sr No	Parameter name	Value
1	Length	20mm
2	Width	20mm
3	Height	1.67mm
4	Substrate material	FR4
5	Ground dimension	20mmx20mm
6	Frequency range	7GHz to 13GHz
7	Band	C and X



(a) (b)

Figure 1: Antenna View (a) Top (b) Bottom

The proposed antenna view is presenting in the figure 1, where the top view shows the design of antenna and bottom view shows the copper layer. The FR4 material is used for the substrate.

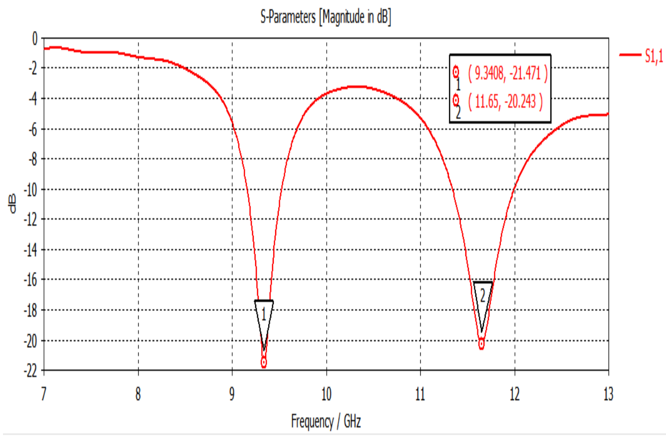
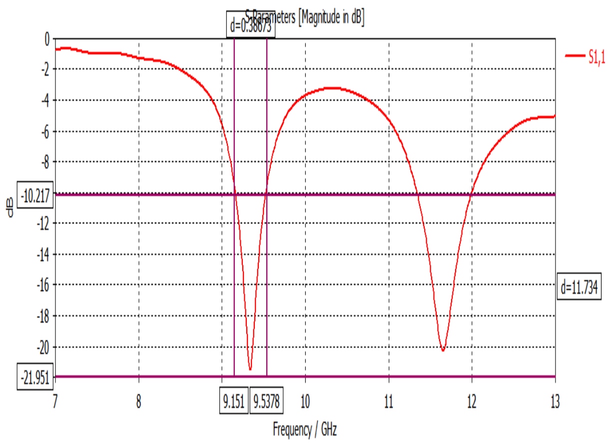


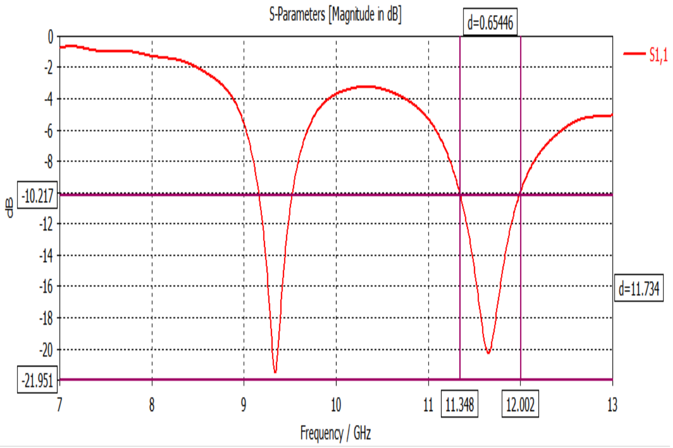
Figure 2: Return loss

Figure 2 shows the achieved return loss values (S11) of -21.47 dB for Band-I and -20.24 dB for Band-II signify excellent impedance matching, indicating that a significant portion of the incident RF energy is efficiently radiated by the antenna.



(a)

 ISSN NO: 1434-9728/2191-0073



(b)

Figure 3: Bandwidth (a) Band-I (b) Band-II

Figure 3 shows the bandwidth results are particularly noteworthy, with the antenna demonstrating a bandwidth of 386 MHz for Band-I and 654 MHz for Band-II. This broad operating frequency range makes the antenna suitable for diverse applications, where the ability to cover multiple frequency bands is essential.

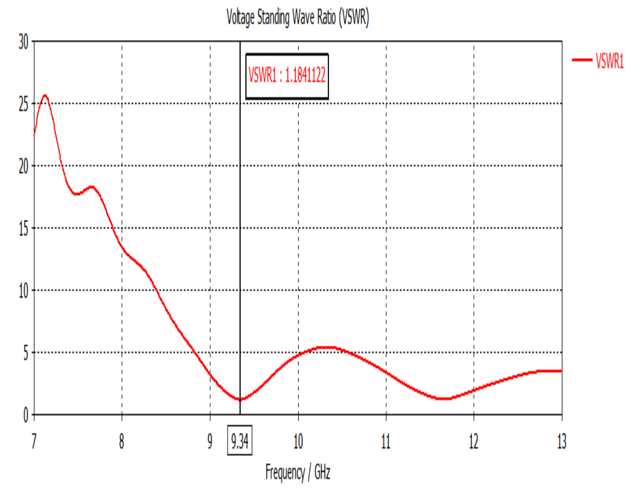


Figure 4: VSWR

Figure 4 presents the corresponding VSWR values of 1.18 and 1.21 further affirm the antenna's effective matching to the transmission line in both bands.

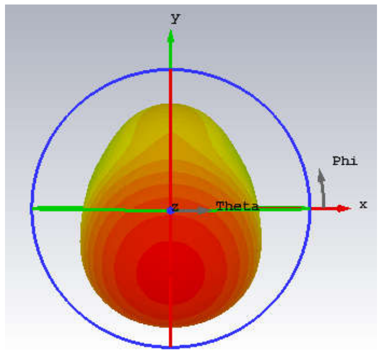


Figure 5: 3D Radiation pattern

Figure 5 shows the 3D radiation pattern. A three-dimensional (3D) radiation pattern is a graphical representation that illustrates how an antenna radiates or receives electromagnetic waves in three-dimensional space. This representation provides crucial insights into the antenna's directional characteristics, helping engineers and researchers understand its performance in different spatial dimensions.

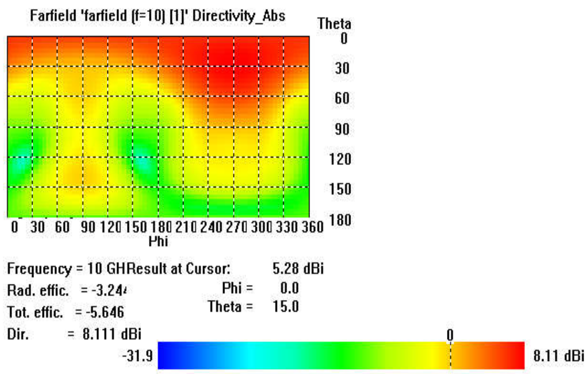


Figure 6: 2D radiation pattern-Directivity

Figure 6 shows the achieved gain of 6.95dBi and directivity of 8.11dBi for Band-I, attest to the antenna's efficacy in directing RF energy efficiently, making it a valuable candidate for communication and radar systems.

Table 2: Antenna simulation results

Sr No	Parameter name	Values for Band-I	Values for Band-II
1	Return loss or S11	-21.47dB	-20.24dB
2	Bandwidth	386MHz	654MHz
3	Resonant frequency	9.3GHz	11.65GHz
4	VSWR	1.18	1.21
5	Directivity	8.11dBi	
6	Gain	6.95dBi	

Table 2: Antenna comparison [1]

Sr No	Parameter name	Previous work	Proposed work
1	Return loss or S11	-14dB, -16dB	-21.47dB, -20.24dB
2	Bandwidth	300 MHz, 580MHz	386MHz, 654MHz
4	Directivity	7.5dBi	8.11dBi
5	Gain	6 dBi	6.95dBi

IV. CONCLUSION

Triple U The Triple U-Slot Microstrip Patch Antenna has shown to be an effective multiband solution for C and X bands, including a small design with remarkable bandwidth and resonance properties. This study enhances microstrip patch antenna technology and paves the way for future investigation and improvement in reaching superior multiband performance. Future endeavors may include experimental validation, refinement of design parameters, and incorporation into practical applications to evaluate real-world efficacy.

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