A Dual-Band T-Slot Microstrip Patch Antenna for Wireless Communication and Radar Application

ABSTRACT

This paper presents a proposed a Dual-Band T-Slot Microstrip Patch Antenna for sub-6GHz 5G application. The proposed antenna is designed to operate at two frequency bands of 5.923 GHz and 7.444 GHz respectively. The size and feed technique are determined by design formulas. The simulation results show a good return loss (reflection coefficient) of -33.696 dB and -18.464 dB respectively which is way below the benchmark of 10dB. The gain and VSWR results are 5.45dB and 1.049 at 5.933GHz; 4.158dB and 1.272 at 7.443GHz respectively. The CST software is used for the simulation.

Keywords: Dual-Band, T-Slot, ROGERS Substrate, Microstrip Patch, WLAN, Radar.

1. INTRODUCTION

The growing demand for high-speed data communication has resulted in the development of a variety of wireless technologies such as Wi-Fi, Bluetooth, ZigBee, and others. Because these technologies operate in the microwave frequency range, antennas are critical components of wireless communication systems [1-2]. In the last ten years, the wireless mobile industry has advanced significantly. It has progressed from fourth generation (4G) LTE systems to the fifth generation's highest data rate (5G). Many countries have installed 4G wireless communication systems. 4G, on the other hand, does not address some issues, such as high data rates, congested spectrum, and high energy consumption [3]. 5G technology operates at frequencies ranging from 600 MHz to 86 GHz. There are two bands of 5G technology. For LTE applications, the first band ranges from 600MHz to 6GHz, while the millimeter wave band spans from 24GHz to 86GHz. To reduce patch antenna size, different patch antenna shapes are proposed [4]. This refers to the use of novel geometries for patch antennas in order to reduce their physical size while maintaining good electrical performance. Wide-band antennas can be designed using a variety of substrate materials, including ROGERS, FR4, Duroid, and Homey Comb [5]. When designing an antenna, it is critical to choose the right substrate material. The cost of an antenna is directly proportional to the substrate's permittivity [6]. The demand for wireless communication systems has increased significantly in recent years, resulting in the development of compact and efficient antenna designs [7].

Microstrip antennas are widely used in modern wireless communication systems due to their low profile, light weight, and ease of integration with other electronic components. The design of a microstrip slot antenna is simple. It consists of a microstrip feed that couples and radiates electromagnetic waves through the slot above. A microstrip fed microstrip antenna provides better isolation between the feed and the material under measurement than a microstrip fed microstrip antenna. In a hybrid MIC and MMIC design, they have greater integration flexibility with other active and passive devices [8]. A substrate with a low dielectric constant and a high thickness provides a wide bandwidth, improved radiation, and increased gain. T-slot microstrip antennas are a type of microstrip antenna with a slot or gap in the radiating patch. According to [9], the T-slot creates an unbalanced current distribution on the patch, which can improve the antenna's bandwidth and radiation characteristics. With an ever-increasing demand for dependable wireless communication, there is a greater need for efficient electromagnetic spectrum use.

Dual-band antennas have gotten a lot of attention because they can operate in multiple frequency bands, increasing the system's flexibility and capacity [10-11]. Because of its compact size, low profile, and simple structure, the T-slot microstrip patch antenna has received a lot of attention among the various types of dual-band antennas [12-13]. The T-slot structure is used to achieve dual-band resonance in a small package, making it suitable for a wide range of applications including WLAN, WiMAX, and satellite communication [14-16]. Because it is easily tuned to operate at two distinct frequency bands, the T-shaped structure is commonly used in dual-band antenna designs. The T-shape structure is also relatively easy to fabricate and compact in size, making it a popular choice for dual-band antenna designs. Dual-band T-slot antennas have been applied in various wireless communication applications, including Wi-Fi, Bluetooth, and mobile communication [17-18]. These antennas' distinct characteristics, such as their small size, low profile, and high radiation efficiency, make them ideal for use in portable and mobile communication devices [19].

2. LITERATURE REVIEW

There has recently been a lot of research into the design and optimization of dual-band T-slot antennas. To improve antenna performance, various techniques such as parasitic elements, defected ground structures, and fractal geometries have been used [20-22]. Furthermore, advanced simulation tools like CST, HFSS, and ADS were used to model and optimize the antenna's performance [23-25]. Despite the availability of numerous design techniques and simulation tools, optimizing dual-band T-slot antennas remain a difficult task due to the complex interaction of the antenna's geometry, substrate properties, and feeding mechanism [26].

A T-shaped slot with a rectangular patch was introduced to achieve dual-band operation in the 2.4 GHz and 5.8 GHz frequency bands for wireless local area networks (WLANs) [27]. [28] proposed a T-slot microstrip patch antenna with a fork-shaped feeding structure to achieve tri-band operation for Wi-Fi, Bluetooth, and 5G systems. In [29], the authors proposed a dual-band T-shaped microstrip patch antenna for wireless communication. The antenna is intended to operate in two frequency bands: WLAN (2.4-2.484 GHz) and WiMAX (2.4-2.484 GHz) (3.1-3.8 GHz). The patch's T-shaped slot is used to achieve dual-band operation. The proposed antenna has good return loss, radiation pattern, and gain characteristics. In addition, the authors compare the performance of the proposed antenna to that of other antennas, demonstrating that their antenna outperforms in terms of bandwidth and gain. Its compact size and simple design make it ideal for practical applications. [30] proposed a dual-band T-slot microstrip patch antenna with a small footprint for WLAN and WiMAX applications. The antenna is constructed from a low-cost FR-4 substrate with a dielectric constant of 4.4 and a thickness of 1.6 mm. A T-slot is included in the patch to enable dual-band operation. The proposed antenna measures 30 x 30 mm2 and has two resonance frequencies of 2.4 GHz and 3.5 GHz, respectively, with bandwidths of 4.16% and 3.43%. The antenna has good impedance matching, stable radiation patterns, and reasonable gains in both bands, according to the simulation results. The proposed antenna is suitable for WLAN and WiMAX applications due to its dual-band operation, compact size, and simple structure.

Other researchers have been investigating T-slot antennas. A dual-band T-slot microstrip patch antenna for WLAN and WiMAX applications was proposed by the authors of [31]. The antenna has resonance frequencies of 2.4 GHz and 5.8 GHz, making it suitable for WLAN and WiMAX applications. The T-shaped slot structure of the proposed antenna was optimized using the CST Microwave Studio software to achieve a compact size and dual-band resonance. A dual-band T-slot antenna for Wi-Fi and WiMAX applications was also proposed in [32]. The proposed antenna has resonance frequencies of 2.4 and 3.5 GHz, making it suitable for WLAN and WiMAX applications. The T-shaped slot structure of the proposed antenna was optimized using the HFSS software to achieve a compact size and dual-band resonance.

[33] proposed a dual-band T-slot antenna for use with Wi-Fi and WiMAX. The proposed antenna has resonance frequencies of 2.4 GHz and 5.8 GHz, making it suitable for WLAN and WiMAX applications. The T-shaped slot structure of the proposed antenna was optimized using the CST Microwave Studio software to achieve a compact size and dual-band resonance. Similarly, for Wi-Fi and WiMAX applications, [34] proposed a dual-band T-slot antenna with a U-shaped slot. The proposed antenna has resonance frequencies of 2.4 GHz and 5.8 GHz, making it suitable for WLAN and WiMAX applications. The U-shaped slot improved impedance matching and radiation characteristics of the antenna, resulting in improved performance. [35] recently proposed a dual-band T-slot antenna for Wi-Fi and WiMAX applications. The proposed antenna resonated at 2.4 GHz and 5.8 GHz, making it suitable for WLAN and WiMAX applications. The proposed antenna's T-shaped slot structure was optimized using the CST Microwave Studio software to achieve a compact size and dual-band resonance.

In this paper, we propose a T-slot microstrip patch antenna that operates at two frequencies for a variety of wireless communication and radar applications. The patch antenna's dual-band operation is achieved through the use of a T-shaped slot. The small size of the antenna (44mm x 41mm). The proposed antenna's performance is measured in terms of return loss, radiation pattern, and antenna gain.

3. DESIGN OF AN ANTENNA

Several steps were taken in the design of the proposed antenna. We begin by defining the design specifications, which include the desired operating frequency, the design substrate material, thickness, and dielectric constant. We determined the patch antenna geometry, including the physical radius and effective radius of the circular patch, feed location, and ground plane size, using the design equations, and gradually adjusted the parameters to achieve the desired resonant frequency. We also created the feeding network, which is in charge of distributing the input signal to each array element. The proposed antenna is a T-slot microstrip patch antenna intended for use in a variety of wireless communication and radar applications operating in the 5 GHz and 7 GHz frequency bands. Computer Simulation Technology (CST) Microwave Studio software was used to design the antenna, which is widely used in the industry for electromagnetic simulation and design. The proposed antenna geometry is designed on a 1.6 mm thick ROGERS RO4450B substrate with a dielectric constant of 3.7 and tangent loss of 0.02. To optimize the antenna's performance parameters such as bandwidth, gain, and radiation pattern, a 3D model of its geometry was generated using CST software.

The T-slot structure was used in accordance with [36] to achieve dual-band resonance in a compact size, and the patch size was optimized to achieve the desired resonance frequencies. The T-shaped slot is 13 mm wide and half the length of the patch and ground plane, which are 44 mm and 41 mm, respectively. Various parameters were changed in the CST Microwave Studio software to optimize the design, and simulations were run to see how they affected the antenna's performance. Among the parameters optimized are the width and length of the T-slot, the length and width of the patch, and the location of the feed point. The optimization process sought to produce a compact design with a wide bandwidth and high gain in both frequency bands.

3.1 Design Equations

The design equations are presented in the following steps to obtain the dimensions:

The width of the microstrip patch antenna is given by

$$W = \frac{\lambda_0}{f_o\sqrt{(\varepsilon_r+1)/2}} \quad (1)$$

Calculation for the effective dielectric constant ε_{reff}

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

Calculation for the length extension ΔL

$$\frac{\Delta L}{h} = 0.142\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.259)\left(\frac{W}{h}+0.9\right)} \quad (3)$$

Calculation for the Length of the Patch

$$L = \frac{C_o}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (4)$$

Where the effective length of the patch L_{eff}

$$L_{eff} = \frac{\lambda_0}{f_o\sqrt{\varepsilon_{reff}}} \quad (5)$$

Calculation for the Ground Dimensions

$$L_g = 6h + L \quad (6)$$

$$W_g = 6h + W \quad (7)$$

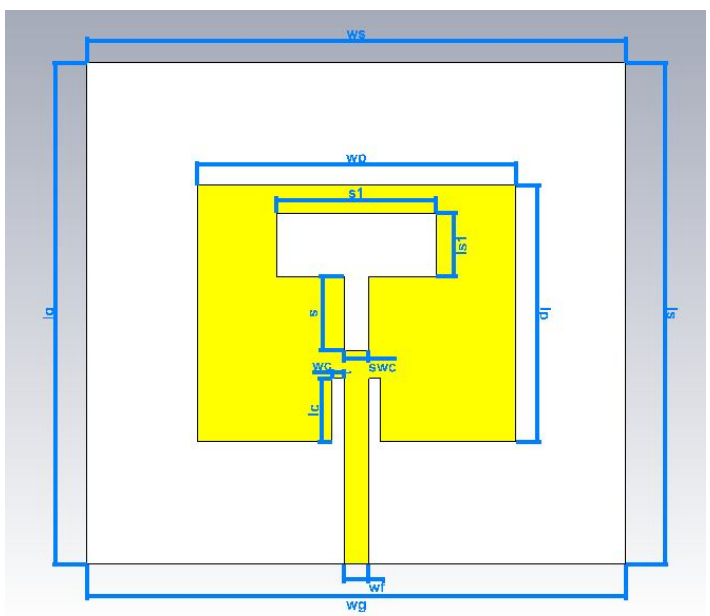

Figure 1: Proposed Antenna Dimensions

Table 1: Simulation Parameters

S/N	Parameters	Description	Values

1	WP	Width of Patch	26 mm
2	LP	Length of Patch	21 mm
3	HP	Height of Patch	2 mm
4	WS	Width of Substrate	44 mm
5	LS	Length of Substrate	41 mm
6	HS	Height of Substrate	1.6 mm
7	WG	Width of Ground	60 mm
8	LG	Length of Ground	56 mm
9	WF	Width of Feed	6 mm
10	LF	Length of Feed	18 mm

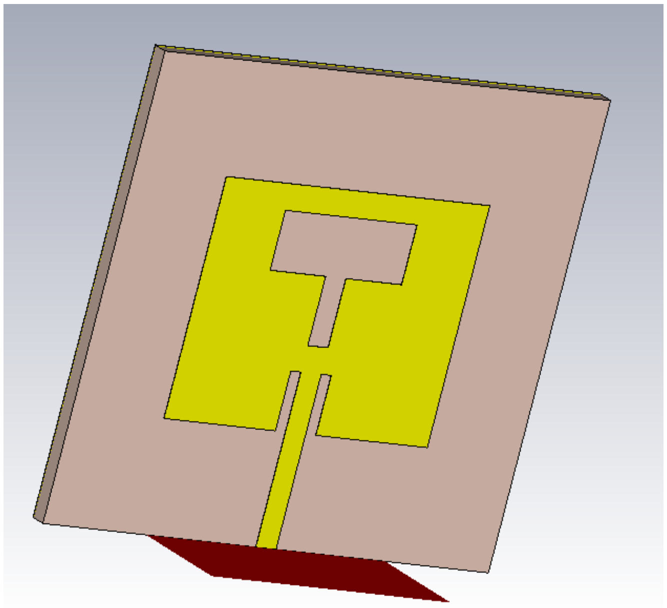

Figure 2: Proposed Antenna Perspective view

4. RESULTS AND DISCUSSIONS

4.1 Return Loss

The difference in dB between forward and reflected power is known as return loss, and it is an important antenna parameter. The return loss of the antenna must be less than -10dB for it to function properly. The simulated return loss v/s frequency plot of the proposed antenna is shown in Figure 4. The proposed antenna had a return loss of -33.696dB at 5.923GHz and a return loss of -18.464dB at 7.444GHz.

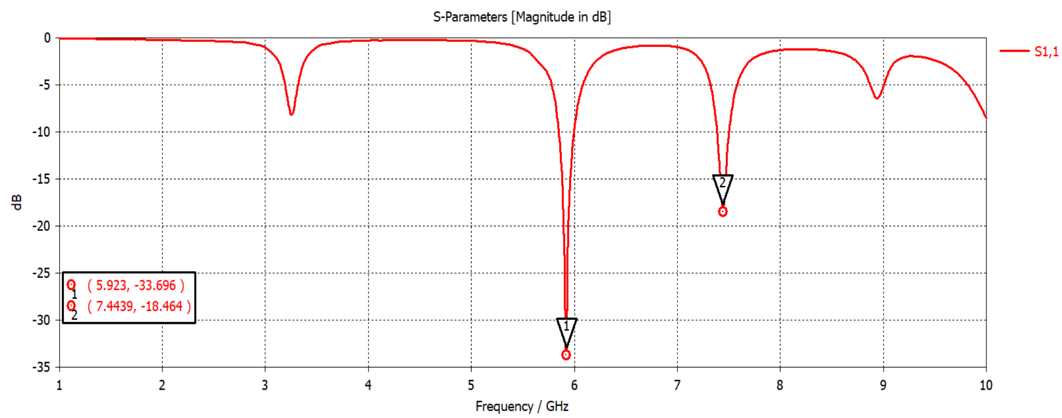

Figure 3: Return Loss (S11-parameters)

4.2 VSWR

The VSWR is a measurement of impedance mismatch between the feed line and the antenna. The mismatch increases the VSWR. The minimum VSWR for perfect impedance matching is one and the maximum VSWR is two. The simulated VSWR v/s frequency plot of the proposed antenna is shown in the figure. The proposed antenna has a VSWR of 1.20 at 5.44GHz and less than 2 for the frequency range of 3.89 to 6.80GHz.

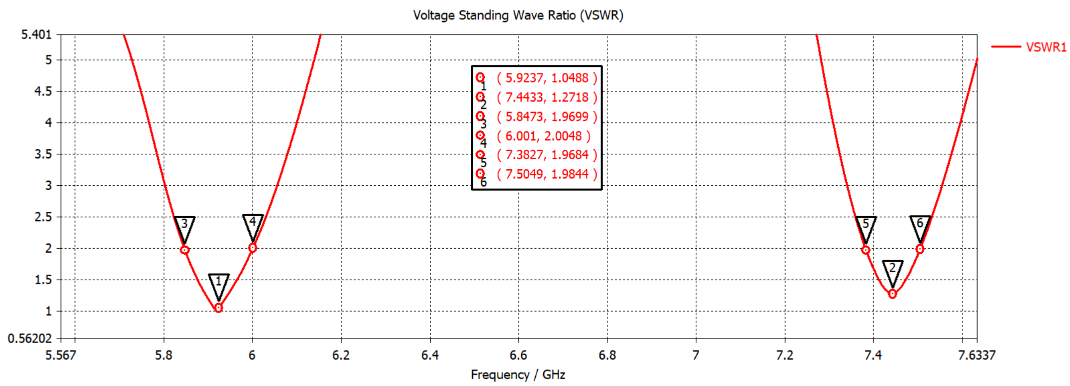

Figure 4: VSWR

4.3 Gain and Radiation Pattern

An antenna's gain describes its efficiency and directional capabilities. The gain value should be greater than 3dB for the antenna to function properly. The proposed antenna has a gain of 6.131dB at 5.933GHz and 4.158dB at 7.443GHz. Furthermore, the proposed antenna has a directivity of 6.97dBi at 5.923 GHz and 5.61dBi at 7.444 GHz. Figures 5, 6, 7, and 8 show the proposed antenna's gain and directivity plot.

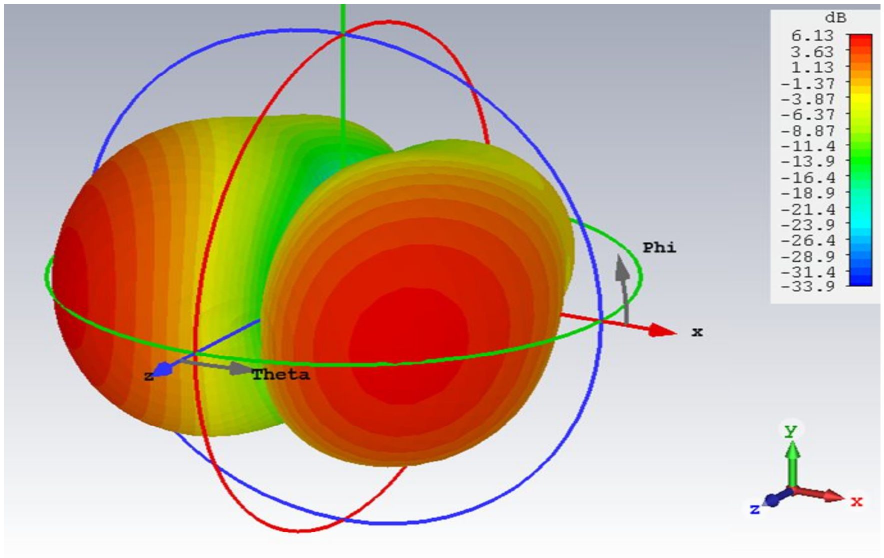

Figure 5: Antenna Gain at 5.923 GHz

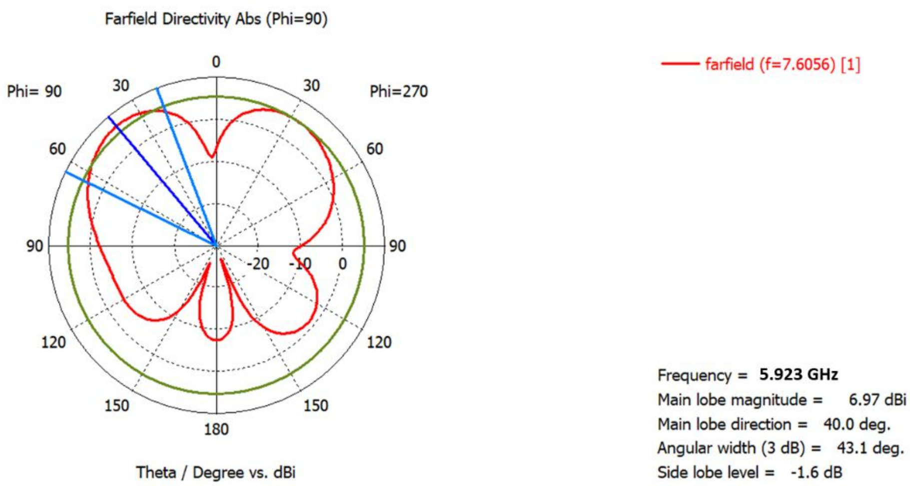

Figure 6: Antenna Gain at 5.923 GHz

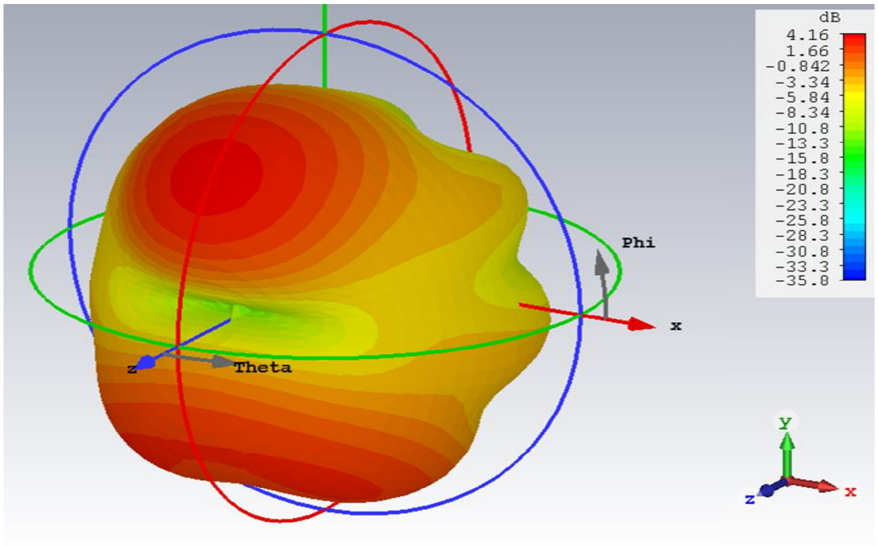

Figure 7: Antenna Gain at 7.444 GHz

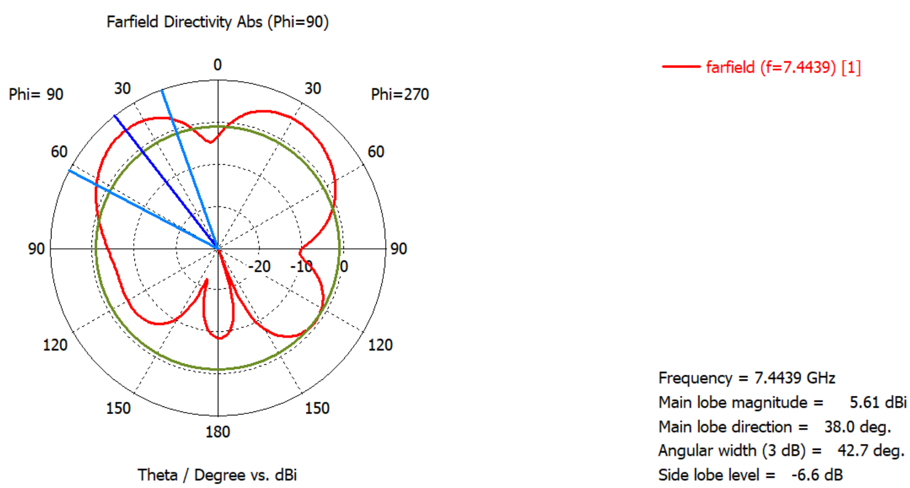

Figure 8: Antenna Directivity at 7.444 GHz

4.4 Comparison of Antennas

The proposed antenna was compared to recently designed Dual-Band T-Slot antennas. The simulation result for the proposed antenna is presented in Table 2, and it can be seen that the proposed antenna has a higher gain at the two resonating frequency bands than the previously designed antennas. Furthermore, as shown by the S11 parameter, the proposed antenna had a very low return loss when compared to the previously designed antennas.

Table 2: Comparison of the Proposed Antenna with existing designs

S/N	Resonant Frequencies	Gain	Return Loss	Reference
1	5.2GHz and 7.5GHz	4.4dBi and 5.5dBi	Less than <10dB	[37]
2	5.24GHz and 6.38GHz	4.5dBi and 4.8dBi	Less than <10dB	[38]

3	5.2GHz and 7.5GHz	4.5 dBi and 5 dBi	-26 dB and -23 dB	[39]
4	5.2GHz and 7.2GHz	4.2dBi and 4.6dBi	Less than <10dB	[40]
5	5.1GHz and 7.1GHz	5.5dBi and 4.9dBi	-20dB	[41]
6	**Proposed Antenna 5.923GHz and 7.444GHz**	**5.45dB and 4.158dB 7.60 dBi and 6.308 dBi**	**-33.696dB and -18.464dB**	

5. CONCLUSION

This paper describes and analyzes the design of a T-shape slot antenna for wireless communication. The antenna is constructed on a ROGERS RO4450B substrate and powered by a microstrip line feed. The results show that the designed antenna's return loss is -33.696 dB and -18.464 dB, which is less than the threshold value of -10 dB, indicating that the losses are minimal during transmission. The antenna has a good gain of 6.131 dB, which is especially noticeable at 5.923 GHz. The dual-band T-slot antenna design has proven to be an efficient and compact solution for wireless communication as well as radar applications such as weather radar and ground surveillance. The design is based on a T-shaped slot and a rectangular patch radiator that have been carefully optimized to achieve dual-band resonance with good impedance matching, high gain, and low return loss.

Future work in this area could include further optimizing the T-slot antenna design for different frequency bands, as well as investigating the impact of various factors on antenna performance, such as substrate materials and antenna dimensions. Furthermore, the integration of multiple antennas into a single system, such as a MIMO (Multiple Input Multiple Output) system, could be investigated to improve data transmission rate and reliability.

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