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Research Article

Square-Framed *T* Shape mmwave Antenna Array at 28 GHz for Future 5G Devices

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In this research, a novel *T* shape antenna is proposed for millimetre-wave (mmwave) 5G systems. Designed on 0.254 mm thin Roggers 5880 substrate with a dielectric constant of 2.3 and the loss tangent of 0.0009, the proposed antenna offers a wideband characteristics of nearly 8 GHz with gain of 4.25 dBi for single element. Based on these characteristics, the single element is further constructed into a four-element linear array with a compact size of $18.5 \times 24\,\text{mm}^2$ The proposed antenna array exhibited dual beam radiation patterns with a high realized gain of 11.5 dBi and 94% efficiency. The measured results from the fabricated prototype well agree with the simulated results and thus, therefore, make the proposed antenna system a well-suited candidate for future mmwave devices.

1. Introduction

With evolution of the universal telecommunication system, 5G technology has now become the centre of interest due to its higher data rates' capacity. The higher data rates are directly associated to bandwidth; therefore, radio frequency (RF) front ends operating at millimetre-wave part of the spectrum have drawn significant attention of the researchers. According to feasibility reports, mmwave spectrum is a promising candidate for 5G services providing high-data rates and low latency over the entire band [1]. Several frequency bands have been allotted for 5G standards including 28 and 38 GHz as most prominent (O2 band) and 164–200 GHz (H2O band) as unlicensed spectrum [2, 3]. As the higher spectrum is free of applications as compared to sub 6 GHz which has immense pressure of application on it, the mmwave spectrum is quite sensitive to the atmospheric attenuations since, in mmwave, the wavelength becomes critically small, and such sensitivity can alter the signal strength which can depreciate experience of 5G. These atmospheric attenuation challenges can be overcome by deploying antennas with high gain levels. Antenna arrays offer higher gain and directivity levels. By implying higher gain antenna assemblies, the atmospheric conditional effects become mitigated and service becomes reliable [4].

Different studies on the mmwave spectrum have shown limitations. The physical dimensions of the antenna systems at mmwave become critically smaller; also, the wavelength becomes critical to fading environments. A four-port antenna system is presented in [5] with conical rings for

28 GHz mmwave applications. The antenna elements are well isolated offering pattern diversity characteristics, but the gain of the MIMO system is very low. Similarly, a nature-inspired four-element MIMO antenna in [6] offers pattern and spatial diversity characteristics, but the bandwidth of the antenna is very low. Substrate integrated waveguides (SIW) are known to have negligible line losses. SIW have been extensively researched in mmwave antenna arrays. In [7], a SIW antenna array offering high gain of 14 dBi is presented. The array has very low-side lobes and offers good dimensions of $63 \times 70\ \text{mm}^2$, but the Vias assembly in the proposed study makes it difficult to assemble in RF circuits. An mmwave antenna array covering 57–71 GHz spectrum with a high gain of 26 dBi is presented in [8]. Although the size of the antenna is relatively small, i.e., $28.8 \times 28.8\ \text{mm}^2$, it is complex in nature to assemble due to its multilayer structure and bonding films. In [9], with the high efficiency of 85%, a four-element array with SIW is presented having the gain of 12 dBi. Although the gain and bandwidth of the proposed antenna is satisfactory, with less than 1 mm apart, Vias present in the structure makes the reported literature too bulky. As compared to SIW, planar antenna arrays are simple and easy to develop [10–12]. In [13], a four-element snowflake antenna array is presented. The gain of the antenna is nearly 10 dBi with narrow beam width for future mmwave devices. In [14], a small 3×3 planar structure is presented in [15] with small size of $400\ \text{mm}^2$ and gain above 15 dBi at 28 GHz, and the relative bandwidth of 1.7 GHz offered by the antenna is very low. Similarly, a super wide band planar antenna offering 17 GHz bandwidth from 23 to 40 GHz is presented in [15] with gain above 10 dBi over the entire band of interest; the size of the antenna is quite large up to $80 \times 80\ \text{mm}^2$ with extensive side lobe levels.

In this paper, a simple *T* shape planar antenna embedded in a frame is presented. The proposed antenna is transformed into four-element linear array in order to increase the gain of the proposed antenna. Through its narrow dual beam width nature, good gain, and efficiency, the proposed antenna can be termed as potential candidate for future RF mmwave devices.

2. Antenna Design

The propose antenna element is designed on ultra-thin Roggers 5880 with relative permittivity of 2.3 and thickness of 0.254 mm. The proposed design is shown in Figure 1. Figure 1(a) shows the front face of the proposed structure, while Figure 1(b) shows the back side of the proposed resonating structure. The length and width of proposed design is 10×12 mm. The dimensions of proposed design are $X = 8$ mm, $Y = 10$ mm, $C = 4.65$ mm, GSX = 1.4 mm, GSY = 1.4 mm, FX = 0.9 mm, FY = 6 mm, $T1 = 2$ mm, $T2 = 2$ mm, $S1 = 3.15$ mm, and $S2 = 3.15$ mm.

The main aim of the design was to resonate at the central frequency of 28 GHz which was achieved with a series of steps. Figure 2 shows the reflection coefficient response of design evolution.

Stage 1 comprised of feed line at 6 mm length which was introduced with a small extension above in stage 2. A horizontal strip was added at the top of extension presented in stage 2, hence forming a *T* shape resonator, but the desired response was not achieved. A square shape frame surrounding a *T* shape was then introduced which produced a strong dip at the central frequency of 28 GHz with bandwidth ranging from 25.2 to approximately 37 GHz, as shown in Figure 2.

2.1. Parametric Analysis. The *s*-parameter response of the proposed antenna was evolved through parametric studies. Figure 3 shows the parametric study details of different antenna parameters. The length of the feed is chosen above 5 mm in order to embed it with the RF connector. The parametric studies presented in Figure 3 show how a small change in a parameter significantly alters the *S*-parameter response.

In Figure 3(a), the impact of feed length on the reflection coefficient is presented. The length of the feed at small intervals of 0.2 mm is observed. It can be seen that, as the length of the feed decreases the reflection-coefficient response decreases in magnitude. At 6 mm length, the feed length exhibits a sharp resonance at the desired frequency of 28 GHz. Similarly, the ground plane of the design is introduced with the square slot at the top-middle section. The optimized value obtained of the square ground slot is 1.4 mm. Now, the length and the width of the slot is change with 1 mm value in range of 1.3 to 1.7, and it is observed that, as the dimension of the square slot increases, the reflection coefficient response is shifted forward and improves in decibels' value.

Figure 3(c) shows the parametric response of the length of $S1$. The length of $S1$ plays a significant role in shifting the resonance from the desired frequency of interest. It is observed that this parameter, also with increasing value, shifts the response to lower frequency position. Also, the value of the reflection coefficient decreases, hence showing the occurrence of impedance mismatch. At last, Figure 3(d) shows the resonance response of the parameter $S2$ which shows that the width of $S2$ affects the impedance matching of the antenna, and as the width decreases, the resonance response gets frail.

Figure 4 shows the performance parameter of proposed antenna. The total efficiency of proposed antenna is above 90% and 97.5% at the frequency of interest with gain ranging in between 4 and 4.5 dBi. The high-performance parameters indicate that the proposed design is highly efficient.

2.2. Array Transformation. The proposed antenna is transformed into four-element linear array for better performance characteristics. Since 5G systems required narrow beam width and high gain, the antenna arrays generally offer such characteristics. A four-element array is prepared using four-element feed network, as shown in Figure 5. The overall dimensions of the four element array is 24×18.5 mm, while the length of the ground plane is 12.85 mm. The surface current distribution has been shown in Figure 6 at 28 GHz which shows that the current is distributed symmetrically between the radiating elements.

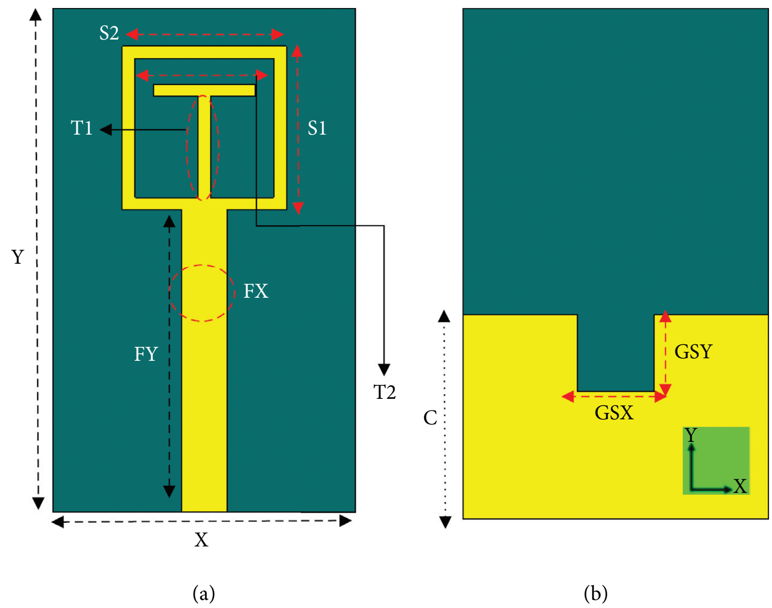


Figure 1: Proposed antenna design: (a) front and (b) back.

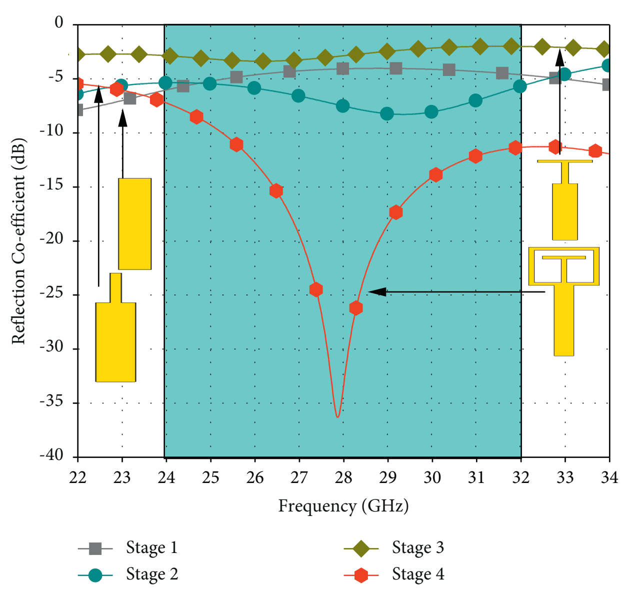


Figure 2: Design evolution.

3. Results and Discussion

The proposed antenna array is fabricated using LPFK machine and is tested using the vector network analyzer. Figure 7 shows the fabricated antenna prototype both front and back side.

The simulated and measured reflection coefficient response of the four-element antenna array is shown in Figure 8. In the resonance bandwidth of the array, although reduced to 25.5 to 30 GHz, a slight shift in the measured reflection coefficient has been observed which can be attributed to the connector, cable losses, or human errors, but overall performance of the system is satisfactory.

The simulated and measured total efficiency with gain over the desired band of interest is given in Figure 9. Both simulated and measured efficiency of the proposed antenna is above 88% in the entire operational band of the antenna. Upon the formation of the proposed single-element antenna into a four-element array, the increase in gain achieved was 7 dBi. Thus, at the main resonance frequency, the gain value achieved is 11.5 dBi, which is very desirable for mmwave systems.

3.1. Radiation Patterns. In this section, the radiation patterns of the proposed antenna array in both principle Phi = 90 and Phi = 0 planes are presented. Figure 10(a) shows

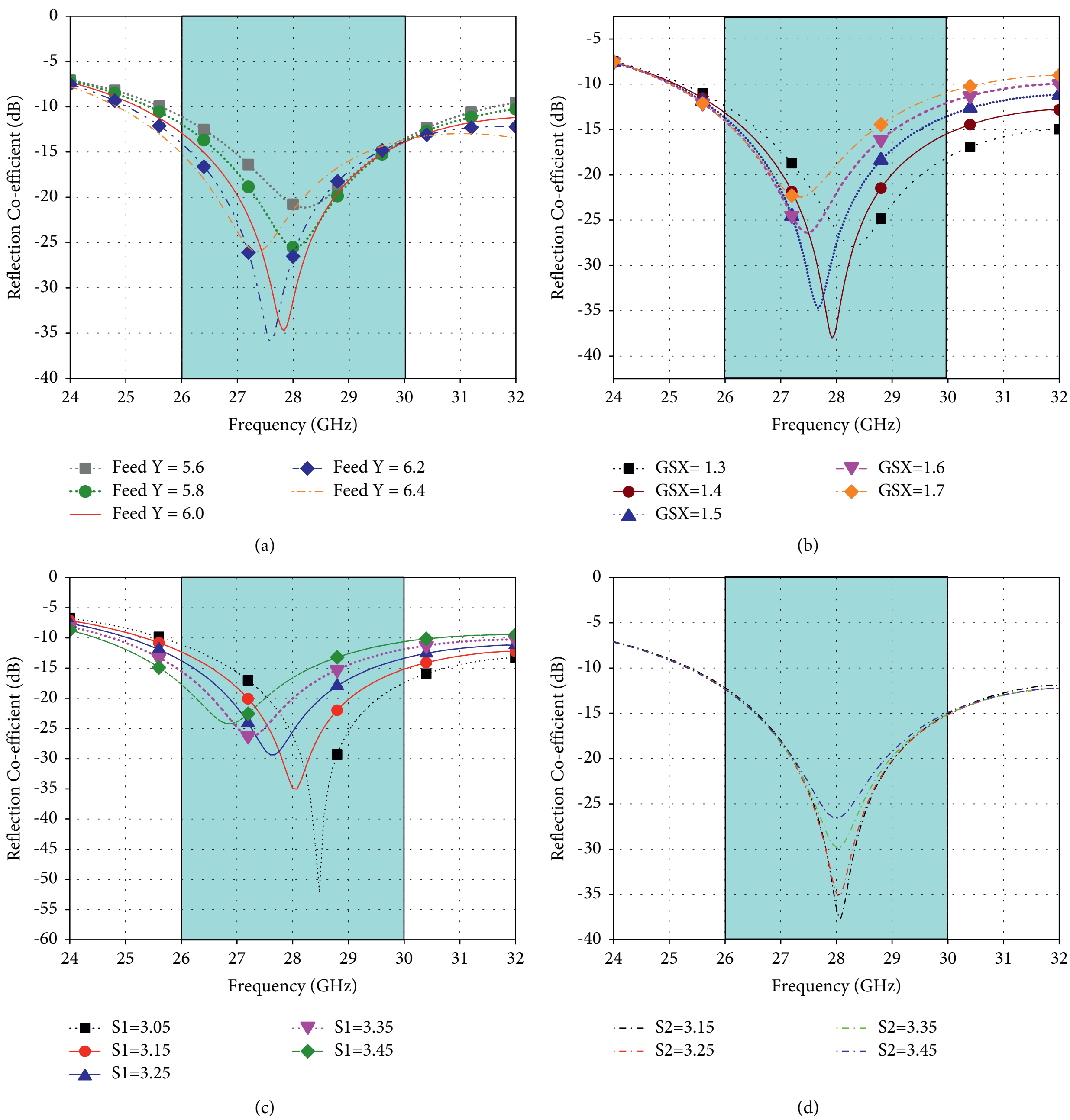


Figure 3: Parametric analysis with respect to (a) FY, (b) GSX, (c) $S1$, and (d) $S2$.

the Phi = 90 plane by which it can be seen that proposed antenna with exclusion of two nulls is radiating in all directions, whereas in Phi = 0 plane, the proposed antenna array is highly directive with the beam width of 20 degrees only. From Phi = 0 plane in Figure 10(b), it can be seen that the proposed antenna offers dual beam characteristics located at 180 degree which can be confirmed by 3D gain radiation patterns in Figure 11. The simulated and measured radiation vary each other with slight variations only. With measured gain of 11.5 dBi and high efficiency, the proposed antenna array can be said as a potential candidate for future mmwave RF devices. Table 1 shows the proposed antenna structure comparison with published literature. From the table, it can be seen that the proposed antenna is simple planar in structure with no complex feeding mechanism. The gain of the antenna is better and the bandwidth of the proposed antenna is better covering the desired band with efficiency 94% at the desired frequency of interest. Hence, it can be concluded that the proposed antenna has good performance characteristics with compact size and thus can be termed as potential candidate for future mmwave RF front ends.

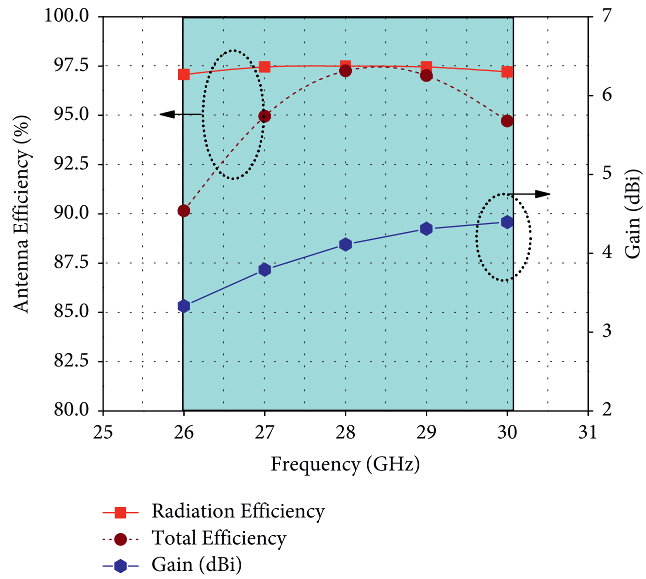


FIGURE 4: Performance parameters of proposed antenna.

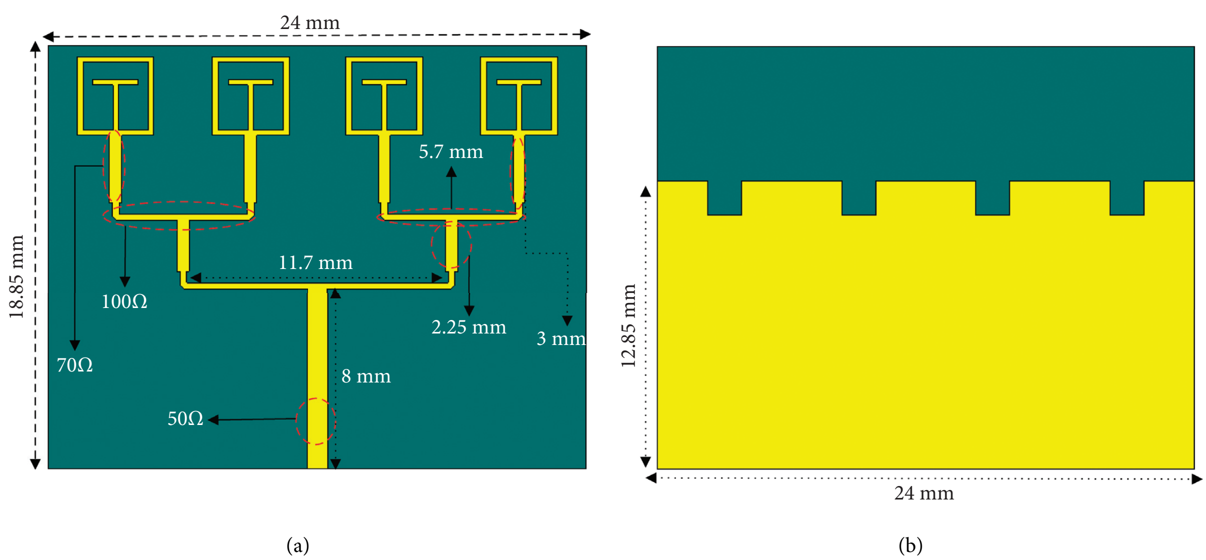


FIGURE 5: Four-element antenna array: (a) front view; (b) back view.

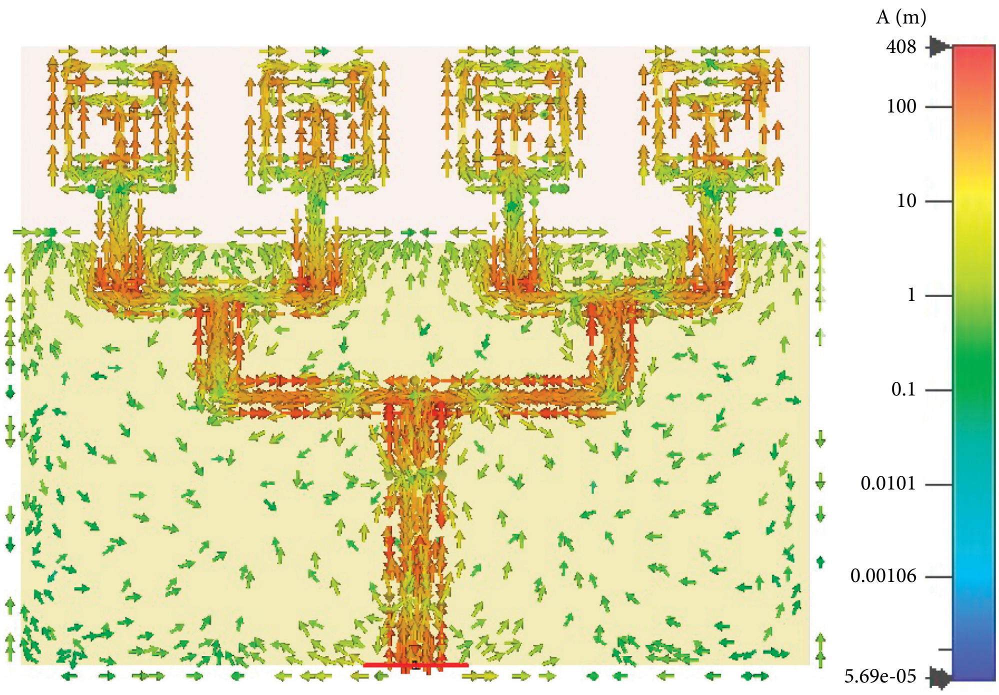
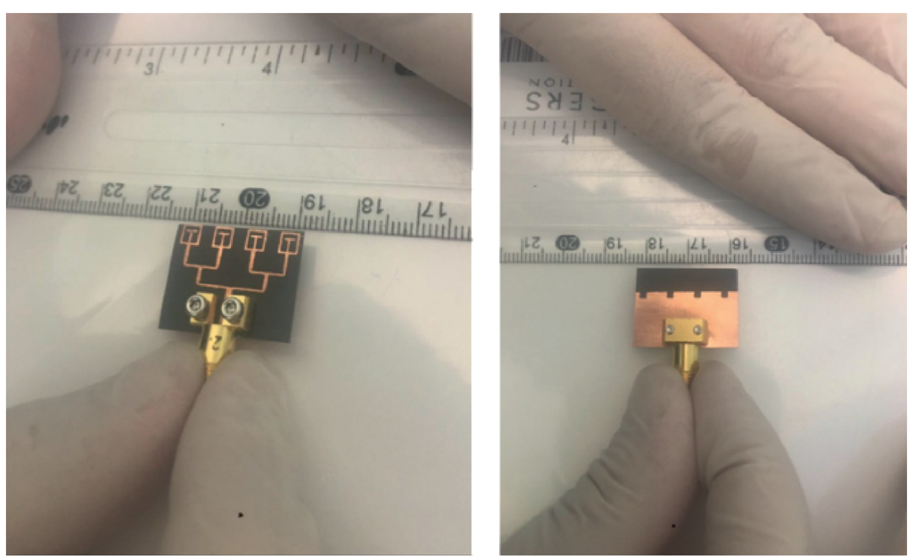


Figure 6: Surface current distribution at 28 GHz.



(a) (b)

Figure 7: Fabricated antenna array prototype: (a) front view; (b) back view.

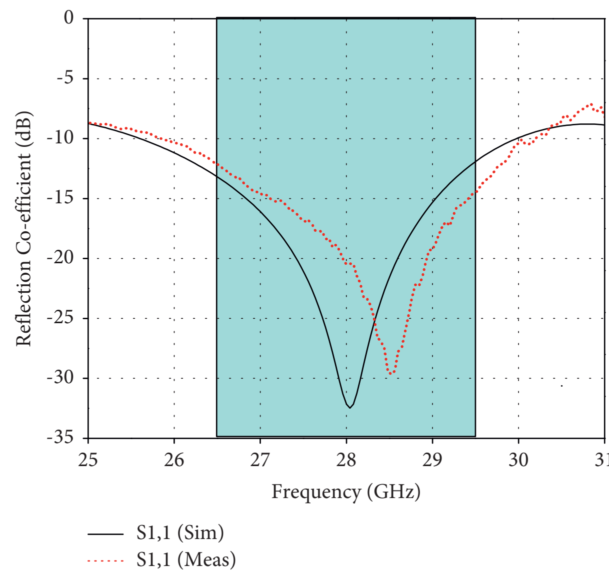


FIGURE 8: Simulated and measured reflection coefficient response of the proposed antenna array.

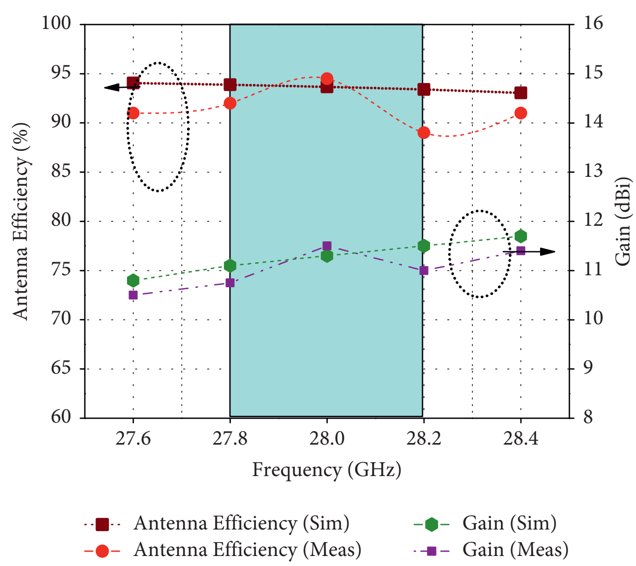


FIGURE 9: Simulated and measured array performance parameters.

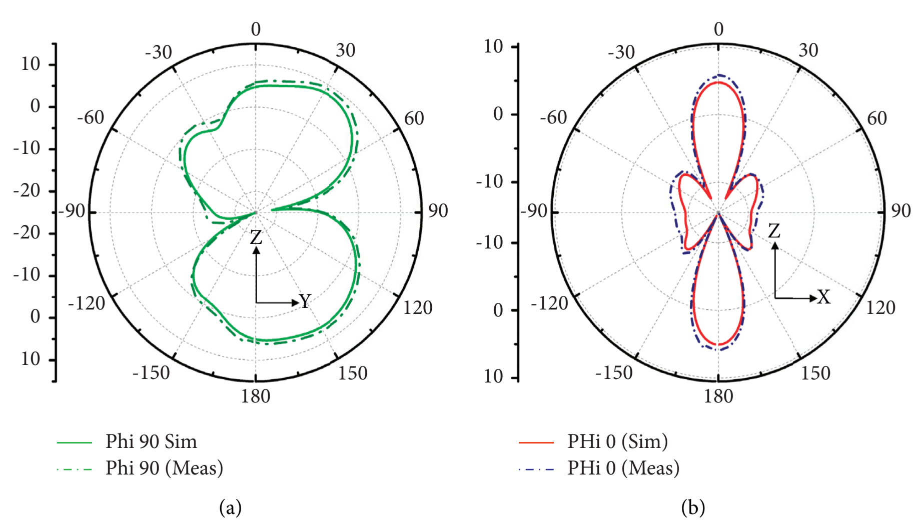


FIGURE 10: Radiation pattern of proposed array at 28 GHz: (a) Phi = 90; (b) Phi = 0.

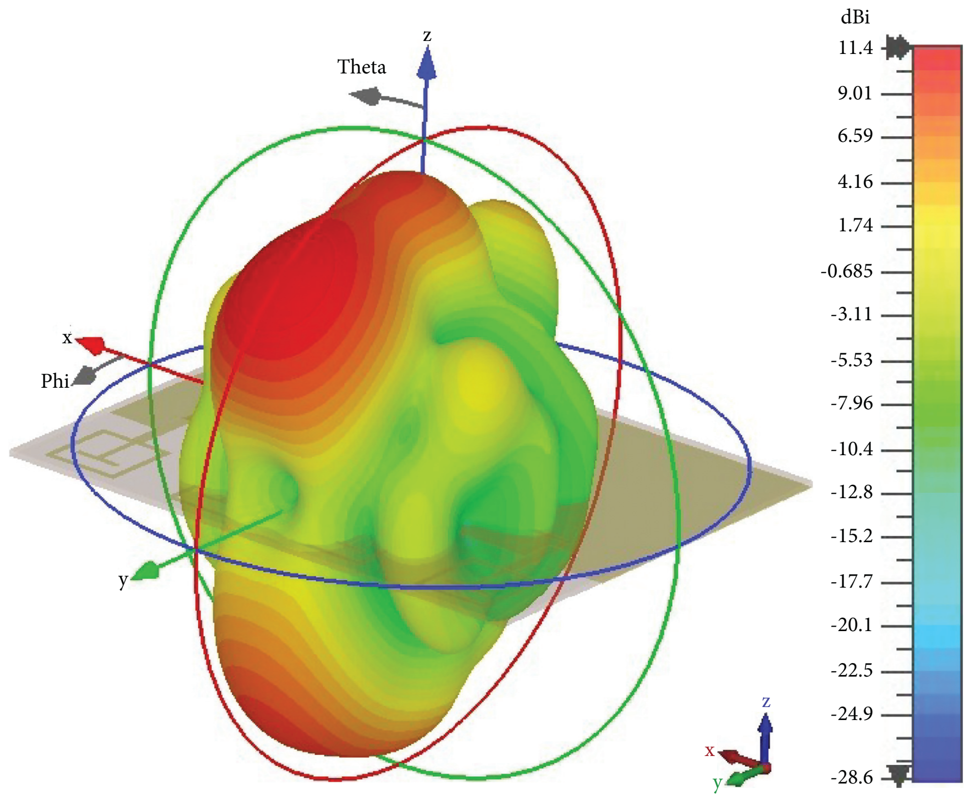


Figure 11: 3D radiation pattern at 28 GHz.

Table 1: Comparison table of proposed antenna with published literature.

Ref	Antenna elements	Configuration	Bandwidth (GHz)	Size in mm (L × W)	Efficiency (%)	Gain (dBi)
5	2 × 2	Planar	3	30 × 30	75	5.5
6	2 × 2	Planar	2.5	30 × 30	78	7
7	1 × 8	SIW	2.3	63.5 70	62	13.5
9	1 × 4	SIW	9	20 × 45	84	12.1
10	1 × 4	Planar	0.6	20 × 26	90	10
15	2 × 2	1 × 4	17	80 × 80	92	11.75
13	1 × 4	Planar	2.9	37 × 14.5	83	10.5
Proposed	1 × 4	Planar	4	18.5 × 24	94	11.5

4. Conclusion

In this paper, a novel *T* shape planar antenna structure is presented for mmwave 28 GHz applications. The gain of the proposed antenna is 4.25 dBi for single element and efficiency is greater than 97% at 28 GHz. The proposed *T* shape antenna is transformed in four-element linear array manner and up to 11.5 dBi of high gain is achieved with radiation characteristics of two narrow beams at 180 and 0 degrees. The overall size of the antenna array is up to 18.5 × 24 mm and the measured results from fabricated prototype well agree with simulated results. Because of efficient performance, features, and unique design, the proposed antenna can be termed as a potential candidate for future high-speed mmwave communication systems.

Data Availability

The data used to support the findings of the study are included within the article.

Conflicts of Interest

The authors declare no conflicts of interest.

Acknowledgments

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