An Ultra-wideband Antenna for Future mm-Wave Applications

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Research Article

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Abstract

This paper introduces a planar ultra-wideband microstrip antenna tailored for millimeter-wave applications. The antenna effectively spans a considerable frequency range from 33.4 to 89.4 GHz. According to simulations, the antenna achieves a peak radiation efficiency of 88 percent, accompanied by a maximum gain of 7 dBi. The antenna design boasts a return loss that remains consistently below -10 dB. The antenna's architecture employs two vertical stubs, strategically employed to regulate the accessible bandwidth. Through optimization of the antenna structure, an impressive bandwidth of 56 GHz can be attained at maximum. The outcomes of the study indicate that the proposed antenna is excellently suited for various millimeter-wave applications, including Ka-band utilization (33.4-36 GHz), 5G cellular communication (33.4-39 GHz), IEEE 802.11ad high-speed wireless systems at 60 GHz, as well as the 57-66 GHz spectrum designated for IEEE 802.15 wireless personal area networks (WPANs).

I. Introduction

The rapid evolution of millimeter-wave technology has been primarily driven by the imperative to attain elevated data rates essential for fifth-generation (5G) and subsequent mm-Wave communications. This progression is accompanied by various benefits inherent to mm-Wave technology, including extensive spectrum bandwidth, substantial communication capacity, robust security features, and formidable resistance to interference. However, it's worth noting that this technology is not without its drawbacks, such as heightened attenuation during inclement weather conditions. Notably, millimeter-wave bands like 26 GHz, 28 GHz, and 38 GHz are designated for utilization in the context of 5G networks [1–3].

Similarly, the Wireless Gigabit Alliance (WiGig IEEE 802.11ad) has spurred researchers to harness the potential of the 60 GHz band to enable exceptionally rapid wireless communication, exemplified by WiFi technology [4].

Nevertheless, the utilization of Ultra-wideband (UWB) within the realm of mm-Wave technology stands out as an emerging field of research in recent times. The synergy between UWB and mm-Wave technology presents notable benefits, such as streamlined RF front-end circuitry and a decreased requirement for discrete antenna elements tailored to different frequency bands. To harness the potential of UWB in the mm-Wave domain, a novel printed dipole antenna has recently been introduced, encompassing a bandwidth spanning 24 to 40 GHz [5]. Other related work includes the UWB antenna for radar and 5G applications (16–40 GHz) [6], wide band narrow beam antenna for 5G mm-Wave applications [7], Quasi Omni directional antenna [8], as well as the compact UWB antenna for 23–65 GHz [9–11].

This paper presents an Ultra-wideband (UWB) antenna designed for the frequency range of 33.4–89.4 GHz is showcased, featuring a consistent gain that peaks at 7 dBi. The antenna design offers extensive coverage across various mm-Wave application bands, including 5G cellular telecommunications, the Ka-band, WiGig communication, as well as the IEEE 802.11ad multiple gigabit wireless system (MGWS) operating at 60 GHz.

This section provides a comprehensive breakdown of the sequential approach employed in the paper. Section II delves into the antenna's design methodology, offering an in-depth exploration. Moving forward, Section III offers a parametric analysis of the antenna, delving into its various characteristics. Section IV elucidates additional outcomes, encompassing aspects such as gain, efficiency, surface current density, and radiation pattern of the newly devised antenna. Section V conducts a comparative examination, pitting the proposed antenna against previous research endeavors. Ultimately, Section VI wraps up the paper by presenting the conclusion drawn from the study's findings.

II. Design Methodology

The motive behind the presented design is to achieve the ultra-wideband characteristics for mm-Wave applications. A symmetric U-shape antenna was designed as a first step as shown in the Fig. 1(a). It was found that the antenna was resonating at a center frequency of 63.92 GHz delivering narrow bandwidth as depicted in Fig. 2.

The antenna can be designed by the following equations [12]. The width and the length of the patch antenna is determined by:

$$W = \frac{C}{(2f_r)\sqrt{\frac{\epsilon_r+1}{2}}}$$

1

$$L = \frac{0.49c}{f_r\sqrt{\epsilon_r}}$$

2

The dimensions of the stub then optimized along with the width of the ground plane to achieve an improvement in the bandwidth ranging from 33.4 GHz to 89.4 GHz. This is demonstrated in Figure. 1(b). The proposed antenna is designed on a 5 mm x 7 mm x 0.254 mm substrate. Roger RT5880 having a relative permittivity, and loss tangent of 2.2, and 0.0009 respectively, is selected as the substrate material. The design consists of a U-shape stub-like structure connected to the feed line. L_L, L_R, and L_F are the lengths of the stubs and feed line respectively, while W_R, W_L, and W_F are their corresponding widths. W_S is the spacing between the two stubs. W_F signifies the feed line’s width of the antenna. W_g represents the width of the ground plane. The optimum values of these parameters are given in Table. 1.

Computer Simulation Technology Microwave Studio (CST MWS) is used to simulate the antenna in time-domain mode. The partial ground plane is chosen as shown in Figure.1 (c).

Table 1: Dimensions of the proposed antenna design

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value(mm)
L	5	W	7	W_g	0.82
W_F	0.68	L_F	1	L_L	3
L_R	0.4	L_1	0.6	W_1	0.6
W_s	0.9	W_2	0.82	W_L	0.6
W_R	0.6				

III. Parameterized Study

Varying different parameters of the antenna leads the good study and explore some valuable insights. The width of the ground plane plays a vital role in controlling the bandwidth. The return loss response was investigated by varying the width of the ground plane as depicted in Fig. 3. The optimized width of the ground plane aids in maintaining the improved bandwidth of the antenna.

Variation in the length of stubs affects the impedance matching characteristics of the proposed antenna. For instance, the antenna demonstrates good matching when the length of the left stub is 3.0 mm and the right stub is 0. 4 mm as shown in Fig. 4 (a) and (b).

Significant alterations are notably observable in the upper-frequency range upon altering the spacing between the two stubs. This observation underscores the significance of the "Ws" parameter in governing the antenna's upper bandwidth limit. This phenomenon is visually depicted in Fig. 5.

Equally noteworthy in the proposed antenna's design is the positioning of the feed line. Modifying the feed line's position yields a transition from a narrowband to a wideband operational profile for the antenna. This transition is graphically illustrated in Fig. 6. This parameter proves to be a valuable tool in effectively regulating the antenna's bandwidth. Specifically, when the feed line is positioned more towards the right, the antenna exhibits a narrowband behavior centered around 60 GHz. Conversely, shifting the feed line towards the left results in a compromised match with the radiation bandwidth shifting to a lower frequency range. Optimal performance is achieved when the feed line is positioned at the center.

IV. Other results

For better understanding and analysis of the antenna behavior, the reflection coefficient of the antenna is divided into six different chunks as ten steps of frequency is used for check the stability of the S1,1 graph as shown in Fig. 7 (a, b, c, d, e and f). The combine graph of reflection coefficient is presented in Fig. 7 (g).

Since the size of the antenna becomes small for the desired bandwidth, the gain of the antenna becomes an important parameter to be investigated. It is found that the proposed antenna maintains a stable gain reaching a maximum gain of 7 dBi. In addition to good gain, the proposed antenna exhibits appropriate radiation efficiency of around 88 percent. Both gain and radiation efficiency are shown in Fig. 8.

The surface current distribution is observed at all resonating frequencies. It is observed that at the resonating frequencies the current is concentrated more at the edges of the radiating patch than its center part. The current first flows to the main feed line and then flows to the right arm of the design and the current density is higher than the left arm. Similarly, mainly the current flow at the edges of the ground plane. The surface current density at frequency 40 GHz is given in Fig. 9.

The radiation pattern of the ultra-wideband antenna is simulated at 40 GHz. Fig. 10 shows the 3-D radiation patterns of the antenna in different planes. Similarly, the 2-D radiation pattern of the antenna in E and H plane is shown in Fig. 11 which shows the high directive nature of the antenna.

The proposed antenna is fabricated as shown in Fig. 12. As the design of the antenna is so compact and needed the advanced measuring equipment. The experimental results did not perform due to unavailability of the Vector Network Analyzer (VNA) and other tools.

V. Comparison with related work

The proposed antenna is evaluated and compared with recent related work as depicted in Table. 2, which shows that the proposed antenna outperforms some of the reported designs in terms of size, gain, and usable bandwidth.

Table 2
Comparison of proposed antenna with previous work

Ref.	**Peak Gain (dBi)**	**Covered Band (GHz)**	**Overall Size (mm x mm)**
[5]	5.8	24–40	10 x > 10
[6]	5.5	16–40	30 x 20
[7]	10.7	23.41–33.92	5 x 9
[8]	5.66	23–33	5 x 6
[9]	5.66	23.5–65	4.6 x 8
[10]	3.44	17.5–45	8 x 6
This work	7	33.4–89.4	5 x 7

VI. Conclusion

This paper introduced a planar ultra-wideband microstrip antenna intended for forthcoming millimeter-wave applications. Within the frequency span of 33.4–89.4 GHz, the antenna design attained a notable gain of 7 dBi and an impressive efficiency rating of 88 percent. The antenna's parameters are meticulously tuned to yield optimized outcomes. A comparative analysis is conducted between the proposed antenna and related prior research efforts. The versatility of the designed antenna is underscored by its suitability for diverse millimeter-wave applications, including employment in Ka-band scenarios, 5G cellular telecommunications, the IEEE 802.11ad multiple gigabit wireless system (MGWS), as well as the IEEE 802.15 wireless personal area network (WPAN).

Declarations

Competing interests: The authors declare no competing interests

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Figures

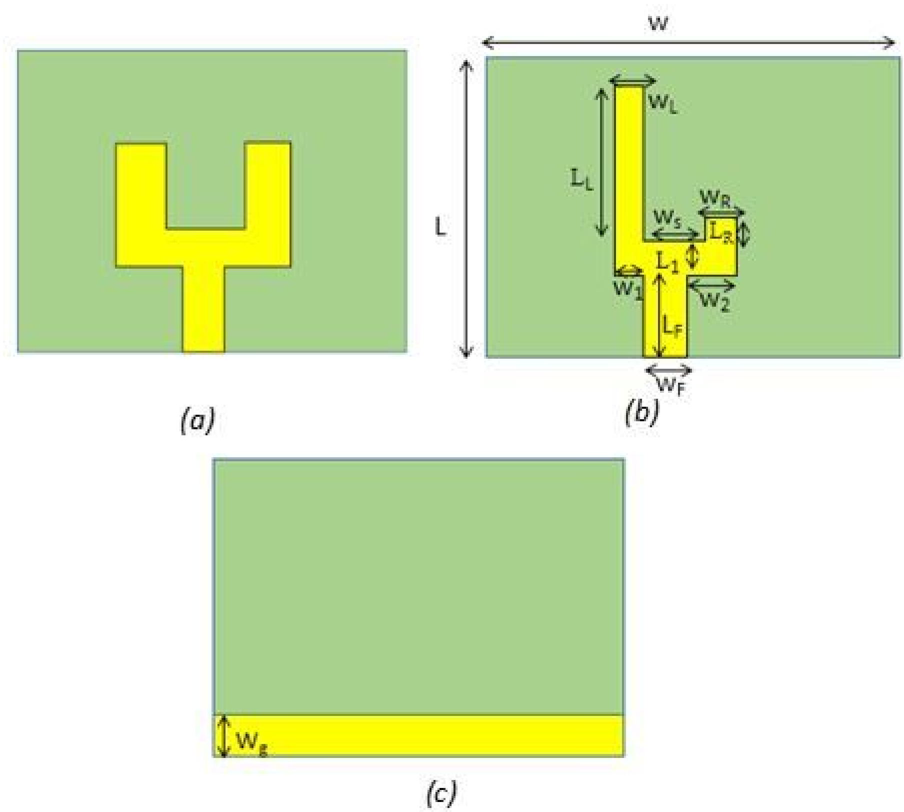


Figure 1

Antenna design strategy (a) Symmetric U-shape (b) Asymmetric U-shape (proposed)

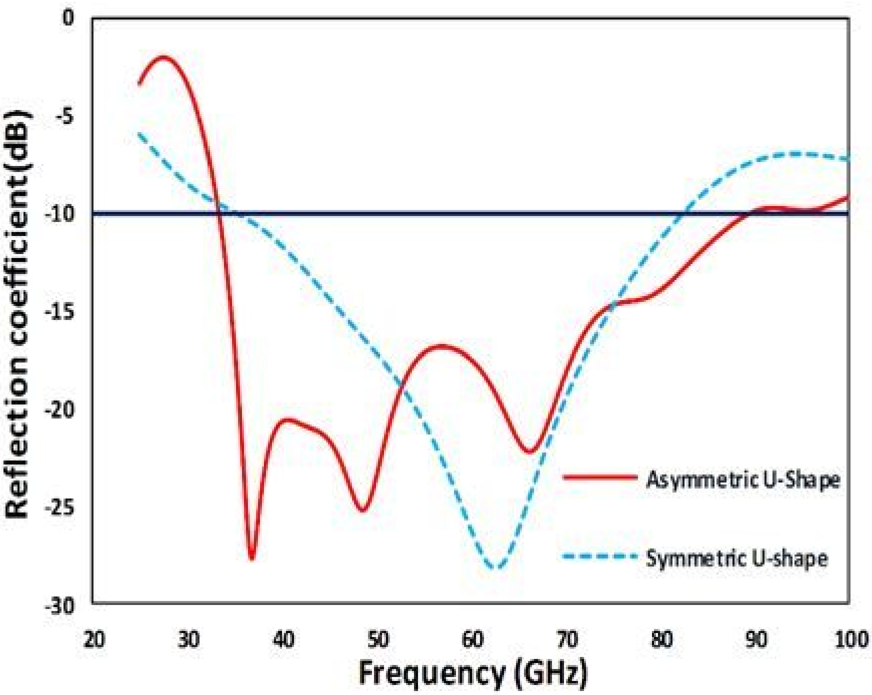


Figure 2

Reflection Coefficient of the initial and final (proposed) design

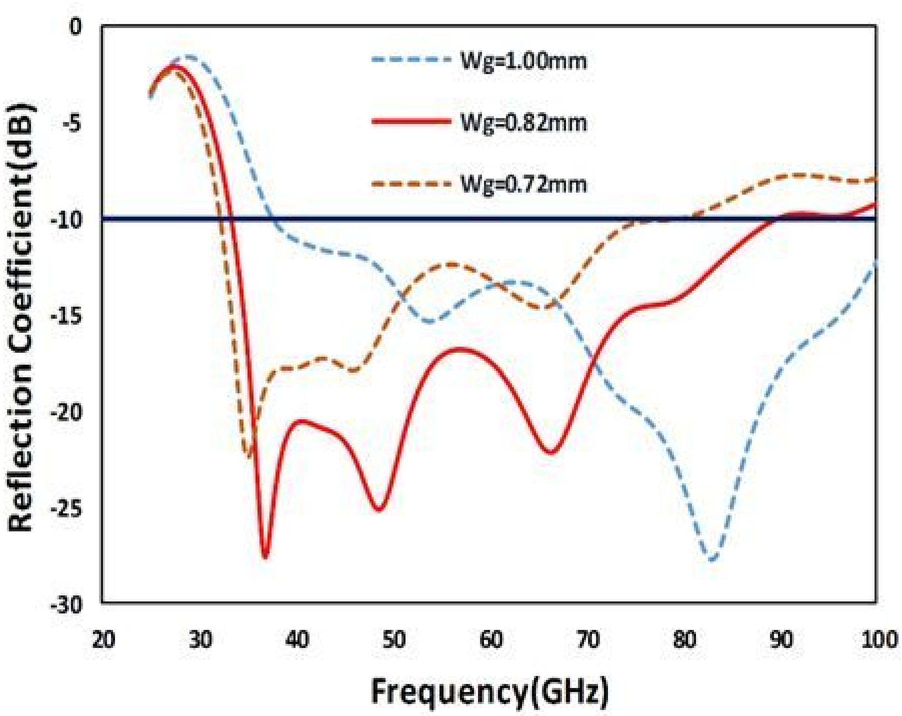
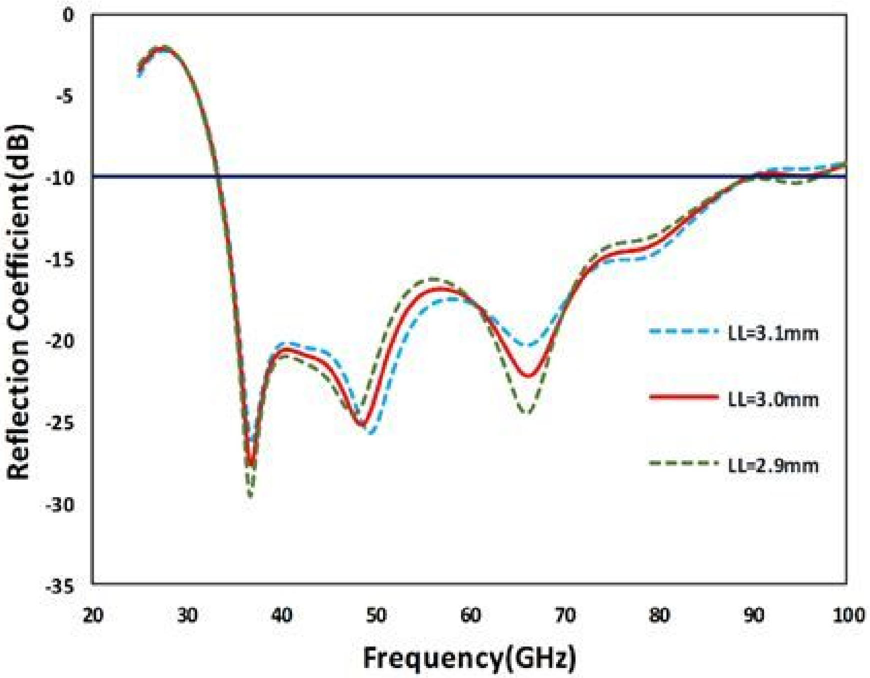
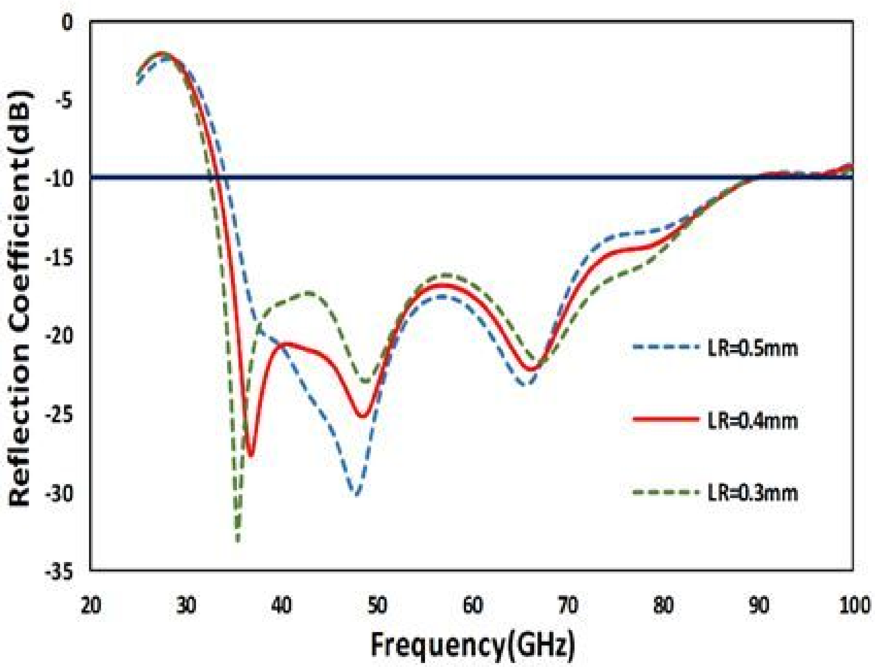


Figure 3

Effect of varying the width of ground plane



(a)



(b)

Figure 4

Effect of varying the length of (a) left stub (b) right stub

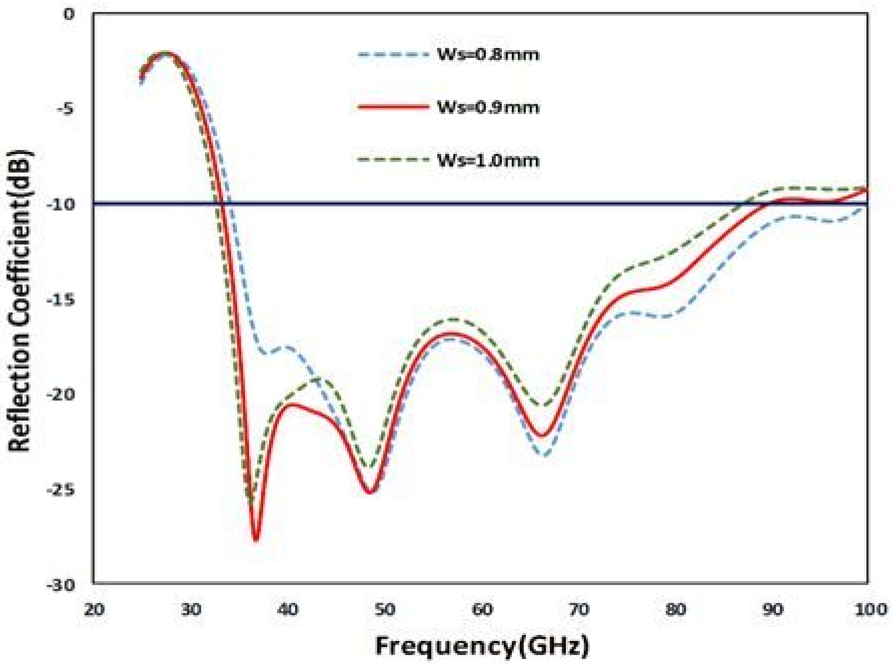


Figure 5

Effect of varying the distance between the stubs of the antenna

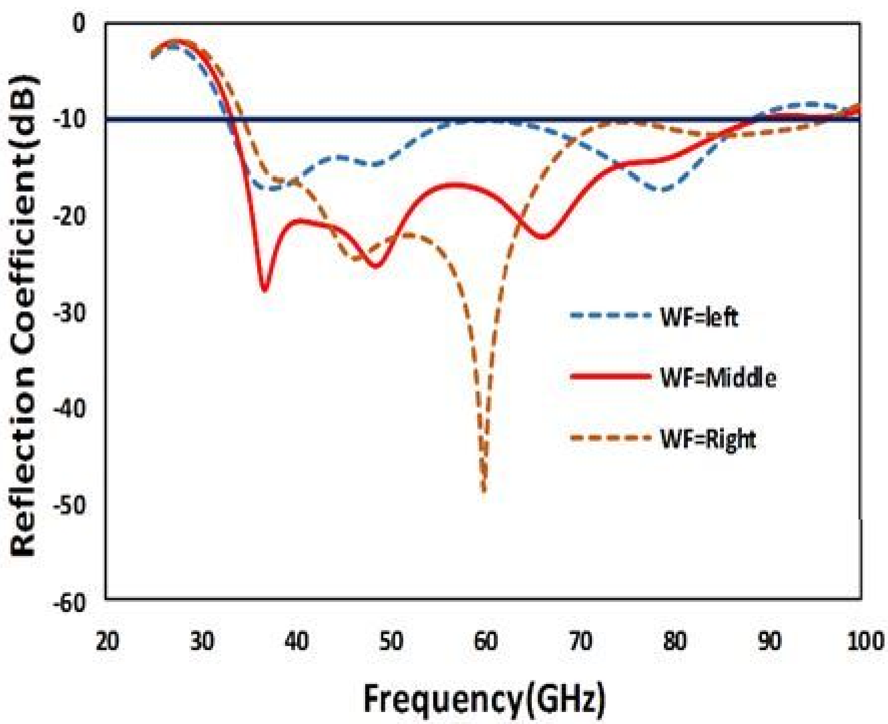


Figure 6

Effect of changing the feed line position

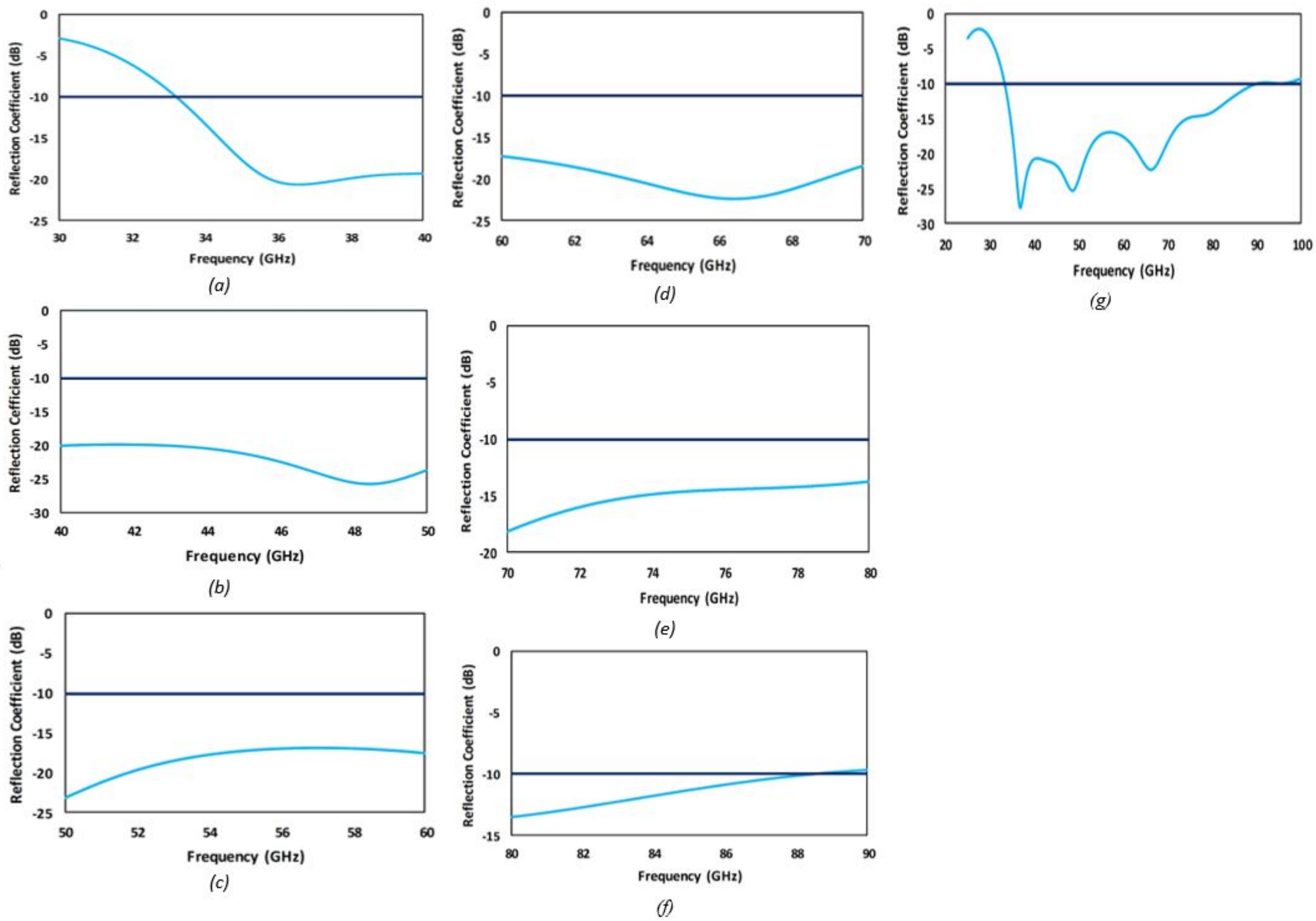


Figure 7

Reflection Coefficient (a-f) in chunks (g) combine result

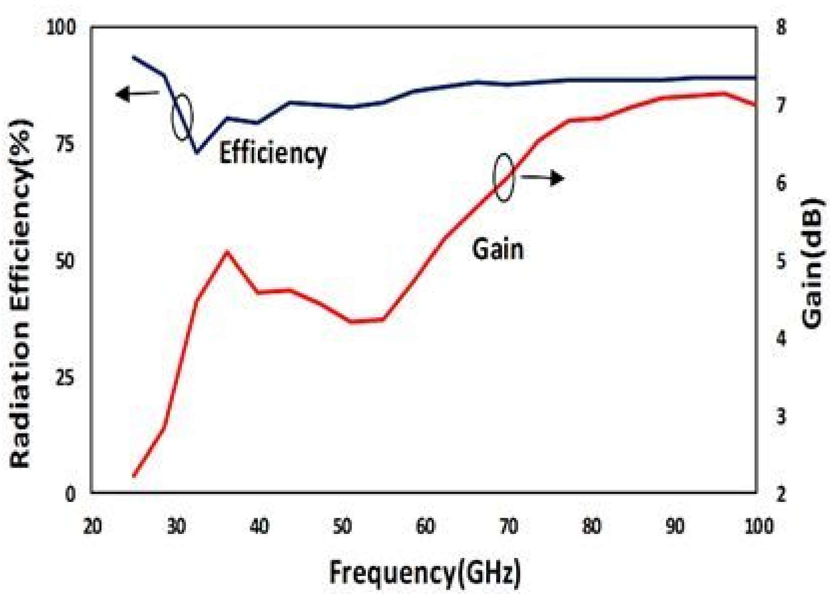


Figure 8

Gain and Efficiency of the antenna

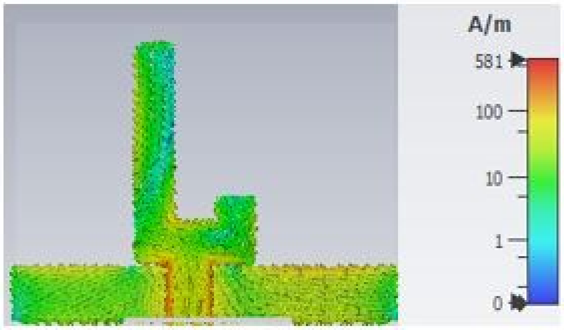


Figure 9

Surface current distribution at 40 GHz

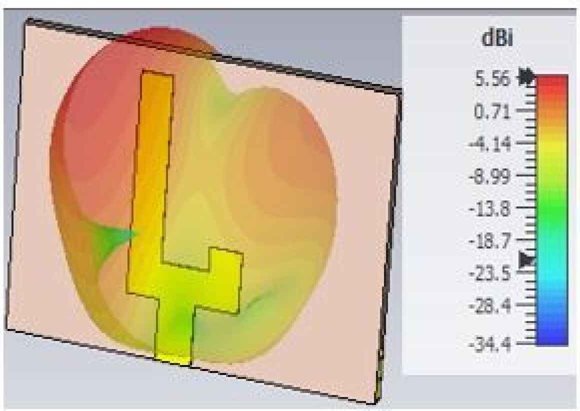


Figure 10

3-D radiation pattern of the proposed antenna

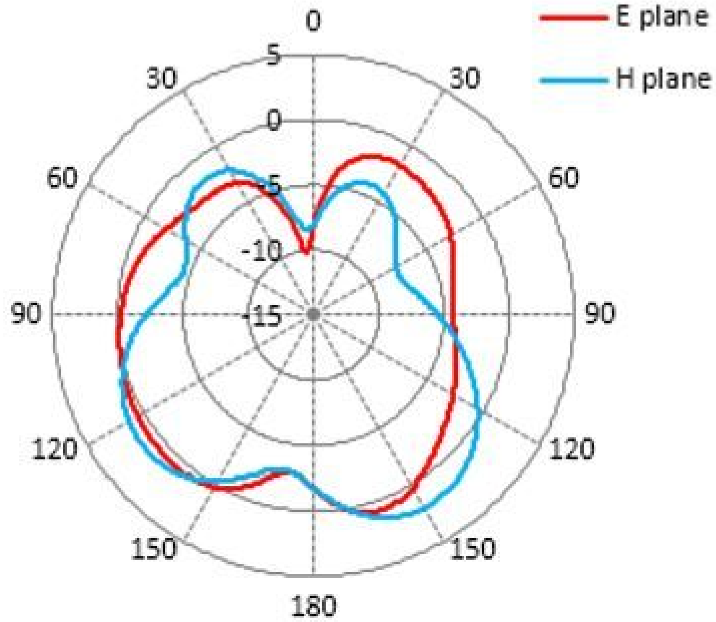


Figure 11

2-D radiation pattern of the proposed antenna in E and H plane

Figure 12

Fabricated design of the proposed antenna