A Compact and Wide Band Antenna for Millimeter Wave Applications

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***Abstract*—A compact and geometrically simple millimeter wave antenna is proposed and discussed in this work. The suggested design contains an inverted L-shaped stub and a circular ring-shaped stub. The antenna is fed at the left corner of the substrate material Rogers 6002. The purpose of the stubs is to increase the antenna's bandwidth and return loss. Furthermore, the antenna operates at the resonance frequency of 28 GHz and provides wideband with a high gain up to 10 dBi. Additionally, antenna results are compared to recent research works. Based on the comparison and outcomes, the presented antenna is an excellent choice for future compact devices operating in the millimeter wave spectrum.**

Keywords— 5G, high gain, ultra-wideband, millimeter wave

I. INTRODUCTION

Rapid advancements have been observed in communication systems since the last decade. These advancements are brought about due to the changes in requirements by end users [1]. The consumer demands a high-speed network with low prices as well as compact and portable devices. Due to this fact, the transformation is noted from 3rd generation to 4th generation and then 4th to 5th generation and future 6th generation [2]. These movements alter the design and requirements of wireless communication networks [3]. Antenna is one of the most important components of wireless systems. The requirement of wireless system changes direly affects the requirements of designing antenna [4]. To get a high-speed network and facilitate the huge number of people without any delay, a wideband and high gain antenna is required. Moreover, to bring compatibility and ease to integration with electronic networks, the compact and simplified geometry antenna is designed [5–6]. To overcome these challenges, researchers have designed several antennas operating on a millimeter wave spectrum. Academics are aiming for high-gain, wideband antennas that are smaller in size and have a streamlined design in order to function on the 24 GHz, 28 GHz, and 38 GHz bands [7]. Nonetheless, a few of the works that are available in the literature are smaller in size but do not function across a large bandwidth.

Wideband antenna operating on 26.4–31.6 GHz is reported in [8] which has a measurement of 20 mm × 20 mm. The antenna offers a high value of gain of 8 dBi. The wideband and high gain are obtained after loading elliptical-shaped patches and slots. A different wideband antenna with a bandwidth of 24.9–30 GHz that operates at 28 GHz is described in [10]. The antenna is small and has an 8.25 dBi gain. These works offer wideband and high gain but have complex geometrical structures [9–10]. A compact and simplified geometry antenna is reported in [11]. The cited work has a size of 15 mm × 20 mm with a simple structure having helical-inspired patches. The reported work offers 26–29 GHz bandwidth with a high gain of 5.9 dBi. In [12], a slot loaded rectangular patch antenna is reported. The antenna offers a bandwidth of 26.6–29 GHz with a central frequency of 28 GHz. The antenna provides a gain of 8.2 dBi with a compact size of 14 mm x 14 mm. This work has a narrow bandwidth as compared to other work presented for millimeter-wave applications.

Keeping in mind the requirements of future communication systems and limitations of previously published work, in this paper compact, simple, wideband, high gain, and high efficiency antenna is presented for future 5G applications. The rest of the paper is organized as; the antenna structure along with the designing steps are explained in section 2. In section 3, the outcome of the antenna is given in the form of an S-parameter, radiation pattern, and frequency and gain plots. The suggested antenna is also contrasted with previous research to demonstrate the superiority of the results that were obtained.

II. ANTENNA DESIGN AND METHODOLOGY

A. Proposed Antenna Layout

The structural layout of the antenna for millimeter wave applications operating over ultra-wideband is given in Fig. 1. The presented antenna structure contains an inverted L–shaped patch loaded with a circular ring-shaped stub. The radiator is fed with a microstrip feedline from the left side of the patch. The rear side of Rogers RT6002, a commercially available substrate material with relative permittivity, loss tangent, and thickness of 2.94, 0.002, and 0.79 mm, respectively, serves as where the suggested antenna is designed. The overall measurements of this UWB antenna are L1 × W1 × H = 10 mm × 10 mm × 0.79 mm.

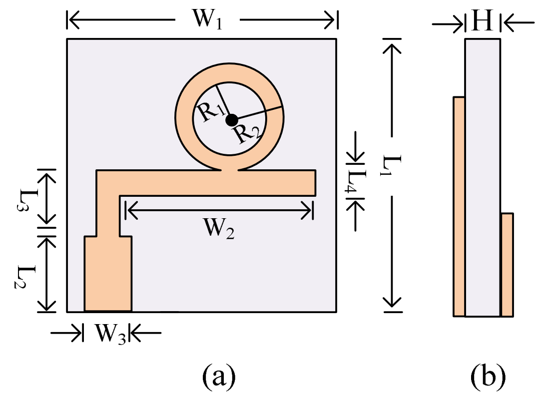

Fig. 1. Geometry of millimeter wave antenna (a) front view (b) side view.

TABLE I. COMPARISON OF PROPOSED WORK WITH RECENTLY PUBLISHED WORKS

Ref	Dimension (mm × mm × mm)	Resonance Frequency (GHz)	Bandwidth (GHz)	Gain (dBi)	Design Methodology
[7]	5 × 5 × 0.762	28	27.5–28.25	7.6	Y-shaped patch antenna
[8]	20 × 20 × 0.762	27.5	26.4–31.6	8	Slot and elliptical patch antenna
[10]	12 × 8.5 × 0.79	28	24.9–30	8.25	E-shaped patch antenna
[11]	15 × 25 × 0.203	28	26–29	5.9	Helical-inspired patch antenna
[12]	14 × 14 × 0.8	28	26.6–29	8.2	Slot-loaded rectangular patch antenna
This Work	**10 × 10 × 0.79**	**28**	**20.2–35.8**	**9.5**	**Circular slot loaded patch antenna**

Additionally, the High-Frequency Structural Simulator (HFSSv9), an electromagnetic (EM) software program, is used to construct, analyze, and investigate several factors related to the provided antenna while applying the proper boundary conditions. The suggested antenna's optimized parameter is provided below. L_1 = 10; W_1 = 10; L_2 = 4; L_3 =2.5; L_4 = 1.5; W_2 = 8; W_3 = 3; R_1 = 1.5; R_2 = 3; H =0.79. (Units in mm).

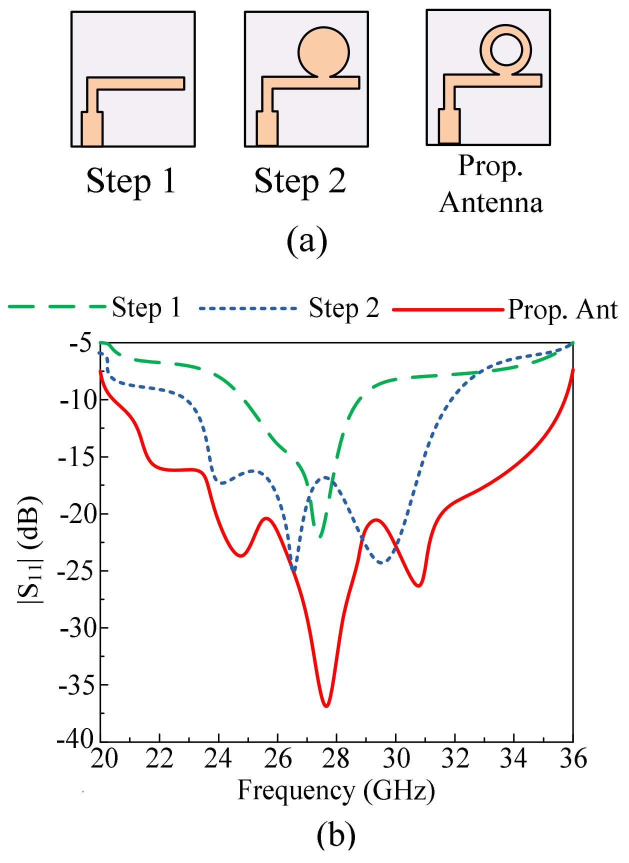

Fig. 2. (a) Various stages to design proposed dual band antenna (b) Impact on various design steps on S11 plot.

B. *Antenna Design Methodology*

To obtain the suggested design final geometry and ultra-wideband results various design steps are followed. The proposed antenna design contains three major steps.

Step 1: In the first step, an inverted L-shaped stub is loaded to the microstrip feed line and partially ground plane antenna. The antenna resonates at 28 GHz with a return loss value of around -18 dB.

Step 2: In the second step, a circular stub is loaded to the top side of the inverted L-shaped stub. The circular stub has a radius of R_2 = 3 mm, as given in Fig. 2(a). After this step, a minor shift in frequency is observed along with an improvement in bandwidth. The antenna starts operating at a wideband of 23 – 32 GHz, as given in Fig. 2(b).

Step 3: The round slot is etched from the circular stub loaded in the preceding step during the last design stage. It is evident that a counterfoil with a ring form forms. As shown in Fig. 2 (b), the resulting antenna operates at an ultra-wideband of 20.2 – 35.8 GHz with a return loss value of -37 dB.

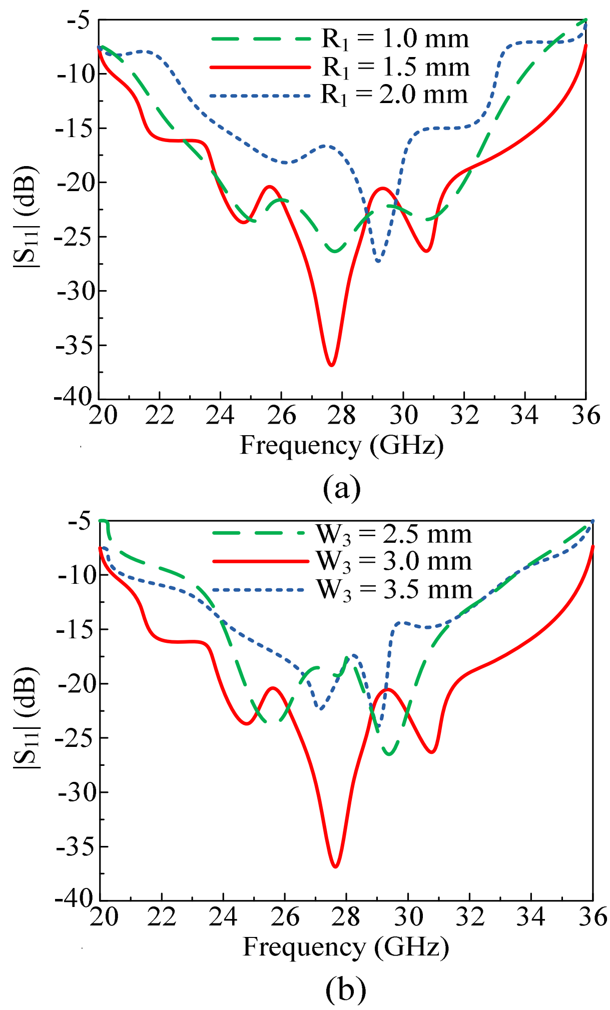

Fig. 3. Parametric analysis of antenna in terms of (a) Radius of slot (R1) (b) Width of feedline (W3).

C. *Parametric Analysis*

To get the optimal design parameters, parametric analysis of the length and width of improvement stubs are performed. For this recommended work, parametric analysis of the radius of the circular slot (R_1) and width of the feedline (W_3) is performed to check and study the impact on the S11 plot. When R_1 = 1.5 mm is at its best, the antenna covers an ultra-wide frequency range of 20.2–35.8 GHz. As shown in Fig. 3(a), the antenna bandwidth and return loss are affected when the value is lowered to 1 mm. When the value is increased to 2 mm, the bandwidth varies somewhat while the return loss varies noticeably. The antenna has a minimum return loss value of -23 dB and operates between 24 and 33 GHz. Conversely, the parametric analysis of the feedline width (W3) is displayed in Fig. 3(b). It can be seen that, when the width is increased from the optimal value to 3.5 mm, the antenna bandwidth is reduced along with the reduction in return loss. Similarly, if the value is fixed at 2.5 mm, again the bandwidth and return loss values are effected.

III. Results and Discussions

A. *S-Parameter*

The scattering parameter (S_{11}) of the ultra-wideband millimeter wave antenna that has been suggested is displayed in Figure 4. The antenna operates at a bandwidth of 15.6 GHz, which covers the frequency range of 20.2–35.8 GHz, as the figure confirms. At 24.5 GHz, 28 GHz, and 31 GHz, respectively, the antenna offers three resonances with the lowest return losses of –24 dB, –38 dB, and –26 dB. For upcoming millimeter-wave compact devices running over wideband, the antenna is the optimum option due to its performance in S11 and ultrawideband operation.

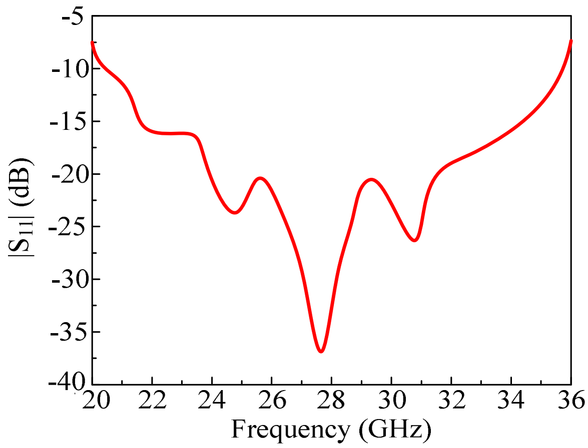

Fig. 4. S-Parameter of suggested ultra-wideband antenna antenna for millimeter wave applications.

B. *Radiation Pattern*

Figure 5 depicts the proposed ultrawideband antenna's radiation pattern at resonance frequencies of 24.5 GHz and 28 GHz. The antenna produces a broadside radiation pattern at both frequencies in the E plane, as shown in the Figure. The radiation pattern at higher frequencies at the H-plane is negligibly distorted and dumbed dell dell-shaped. The slot etching and side feeding are to blame for the little distortion in the radiation pattern. Since the overall pattern of antenna radiation is steady, the suggested approach is a good fit for upcoming 5G small and portable devices.

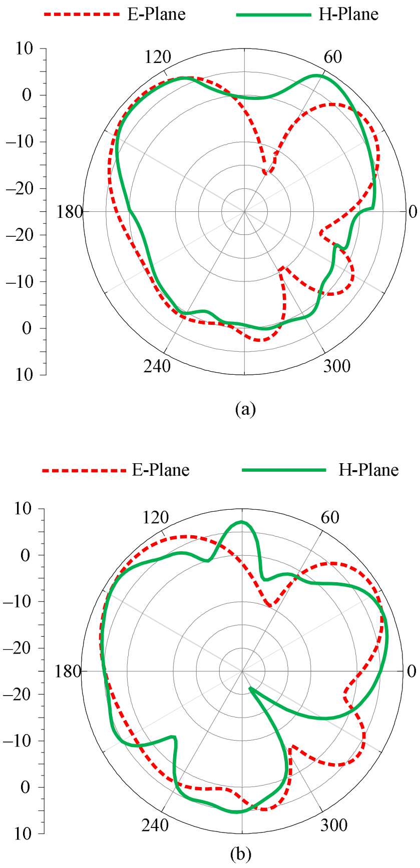

Fig. 5. The radiation pattern of the proposed antenna at (a) 24.5 GHz and (b) 28 GHz.

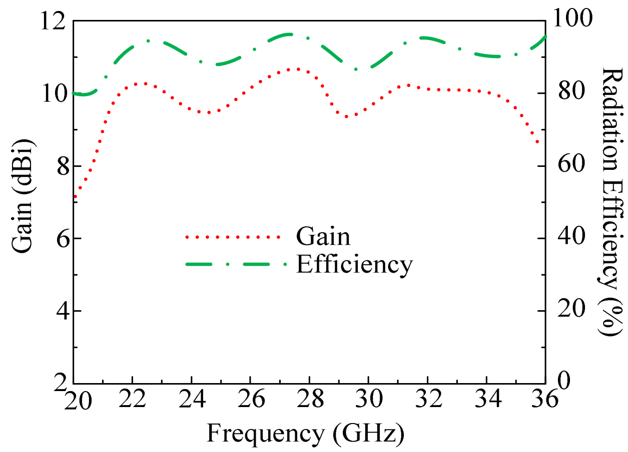

Fig. 6. Gain and Radiation Efficiency of suggested ultra-wideband antenna for mm-wave applications.

C. *Gain VS Frequency Plot*

Figure 6 shows the gain vs frequency curve of the recommended wideband antenna. The antenna has a gain of more than 9.5 dBi over the operational bandwidth of 20.2–35.8 GHz, as the figure illustrates. At 28 GHz, the antenna gain achieves its maximum of 10 dBi, while at 30 GHz, it hits

its lowest of 9 dBi. The recommended antenna's gain value makes it a good choice for high gain, wideband devices in the future. The suggested work's radiation efficiency is also displayed in Fig. 6. The figure makes it evident that the antenna's operating bandwidth of 20.2–35.8 GHz allows for a high radiation efficiency of > 84%. At 24.5 GHz, 28 GHz, and 32 GHz, the radiation efficiency value is high and approaches 97%.

IV. CONCLUSION

In this study, an antenna operating at ultra-wideband is proposed for upcoming millimeter-wave applications. The antenna is small and has a straightforward geometric design. The suggested work provides good radiation efficiency, a wide bandwidth of 20.2–35.8 GHz, and a high gain of 10 dBi. Moreover, the suggested work is a contract, and performance is analyzed by using the EM tool HFSS. Antenna results are also contrasted with previously published research. According to the antenna results and literature comparison, this work is a strong and best applicant for use in upcoming 5G portable devices that operate at high gain and wideband.

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