Equilateral Triangular Slot-based Planar Rectangular Antenna for Millimeter-wave Applications

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***Abstract*—The design of an equilateral triangular slot-based planar rectangular antenna is presented for wideband millimeter-wave (mm-wave) applications. The front-side of the proposed antenna is composed of a rectangular patch radiator with an equilateral triangular slot fed using a 50Ω microstrip feeding line, while the bottom side of the antenna consists of a partial ground plane. To achieve maximum impedance matching in the operating bandwidth, the position of the feeding line is shifted from its normal location. The overall dimensions of the antenna are noted to be 6.5×8.5 mm^2. From the simulation results, it is demonstrated that the -10 dB impedance bandwidth of the proposed antenna is 16.86 GHz, ranging from 22.28 GHz to 39.14 GHz, while at -15 dB, it is equal to 12.82 GHz in the frequency range of 24.18-37 GHz. The gain of the proposed antenna fluctuates in the range of 3.89-6.86 dBi with an antenna efficiency of >85%.**

Index Terms*—*phased array; millimeter-wave; beam steering; cost-effective.

I. Introduction

Fifth-generation (5G) millimeter-wave (mm-wave) spectrum has evolved as a prominent solution because it offers high bandwidth, low latency, and higher data throughput [1]. A large bandwidth is required to provide a high data rate, which can be done by using higher frequency bands [2]. To fully meet these demands, mm-wave frequency bands are the best option. Several bands have been identified as viable options for future 5G standards in mm-wave communication systems, including the 28/38 GHz bands, 57–64 GHz (O_2 band), and 164–200 (H_2O band). The 26 GHz (24.25-27.5 GHz) and 28 GHz (26.5-29.5 GHz) frequency bands are the world's most significant because they enable operators to achieve the highest levels of speed, dependability, latency, and capacity. With their allocation, there is a need to design antennas that are small in size, have large bandwidth and high gain [3], and can easily be accommodated in mm-wave communication devices. Various antenna ideas for 5G communication systems have been offered by numerous researchers. These antenna types include ubstrate Integrated Waveguide (SIW) antennas [4], [5], empty SIW (ESIW) antennas [6], and planar antennas [7]–[9]. From these structures, planar antenna configurations are the most suitable because their fabrication is simple, cost-effective, and they can easily be installed in compact communication devices.

In this paper, a simple and compact equilateral triangle-loaded rectangular patch antenna is designed for wideband mm-wave communication systems. The proposed antenna design offers a high impedance bandwidth of 16.86 GHz in the frequency range of 22.28-39.14 GHz with an antenna efficiency and peak gain of >85% and 6.86 dBi, respectively. In addition, the proposed antenna structure is simple and easy to fabricate.

II. Millimeter-Wave Antenna Design

Figure 1 depicts the design of the proposed planar antenna. The top-side of the antenna element is comprised of an equilateral triangle loaded rectangular patch, which is fed through a 50Ω microstrip feeding line, while the back-side consists of a partial ground plane, which is used to acheive a wide impedance bandwidth. For the antenna design, a low-loss dielectric substrate, Rogers RT/Duroid 5880, is utilized. The thickness of the substrate is chosen to be 0.51 mm with a dielectric constant of 2.2. The overall dimensions of the antenna are noted to be $W_S \times L_S$ = 6.5×8.5 mm^2. The rest of the design parameters are: W_P = 5, L_P = 6, W_1 = 4, L_1 = 5, W_2 = 1, W_F = 1.4, L_F = 2, and L_G = 1.8 (all dimensions in mm).

The design process of the proposed antenna consists of three steps. First, a conventional rectangular patch antenna is designed with a partial ground plane, as shown in Fig. 2(a). It can be observed from the result of Fig. 3 that the rectangular patch is unable to resonate. In the second step, an equilateral triangular slot is etched from the rectanuglar patch (see Fig. 2b) to excite higher-order modes. The addition of a slot in the patch resulted in a wide impedance bandwidth in the desired band (see Fig. 3). To further extend the bandwidth and to achieve maximum impedance matching, the position of the feeding line is changed from x = 0 to x = 0.3 mm, as shown in Fig. 2(c). This change shifts the lower frequency response to 22.28 GHz and the upper frequency response to 39.14 GHz.

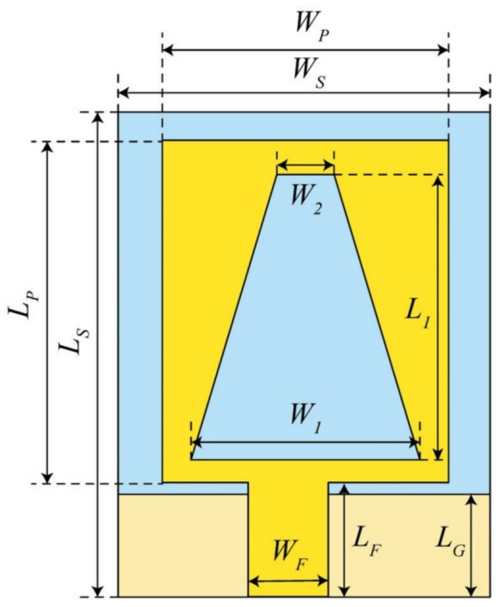


Fig. 1. Schematic of the proposed mm-wave antenna.

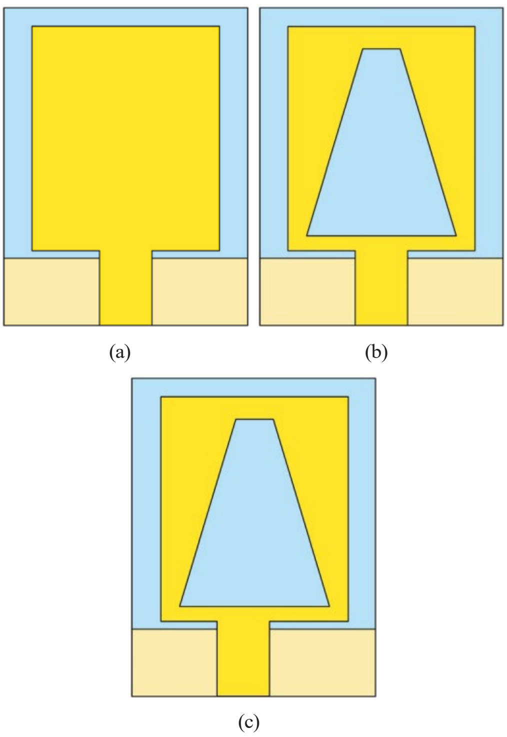


Fig. 2. Design evolution of the proposed mm-wave antenna (a) Step-1, (b) Step-2, and (c) Step-3 (Proposed).

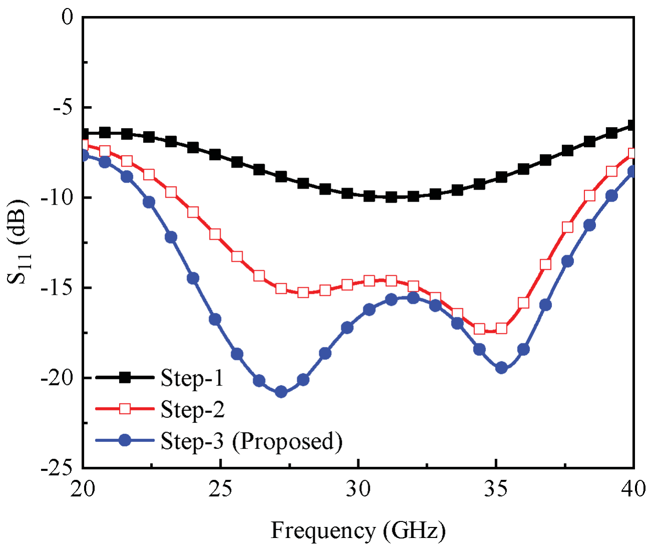


Fig. 3. Simulated reflection coefficients (S_{11}) for different design stages.

III. Simulation Results and Discussion

Computer Simulation Technology (CST) Microwave Studio 2021 was used to design and simulate the proposed wideband antenna. The simulated reflection coefficient (S_{11}) response of the proposed antenna is shown in Fig. 4. The antenna operates from 22.28 GHz to 39.14 GHz according to -10 dB impedance bandwidth criteria, whereas it resonates in the frequency range of 24.18-37 GHz according to -15 dB criteria, as shown in Fig. 4. The noted impedance bandwidths for both the ranges are 16.86 GHz and 12.82 GHz, respectively. These results demonstrate that the designed antenna is a suitable candidate for mm-wave 5G applications because it provides wide bandwidth, which is the basic requirement for mm-wave communication systems.

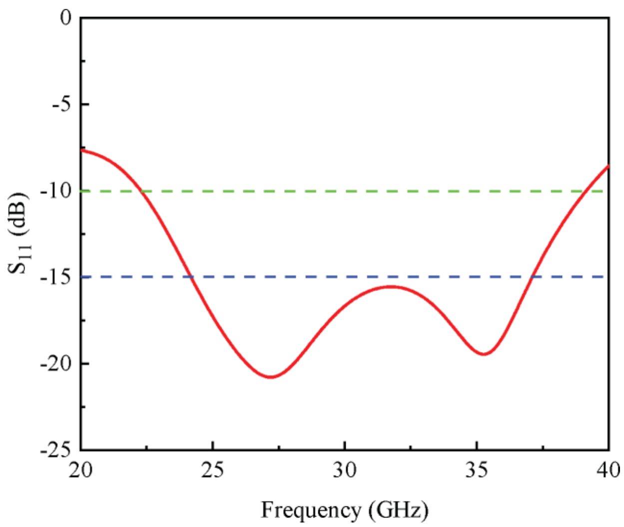


Fig. 4. Simulated reflection coefficient of the proposed mm-wave antenna.

In Fig. 5, the antenna efficiency and realized gain are plotted. The efficiency of the proposed antenna is noted to be more than 85% throughout the desired bandwidth, while the total gain varies from 3.89 dBi to 6.86 dBi (see Fig. 5).

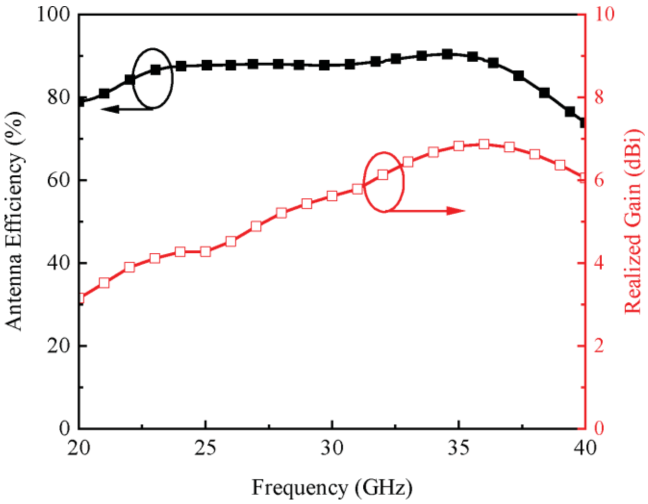


Fig. 5. Simulated antenna efficiency and realized gain of the proposed mm-wave antenna.

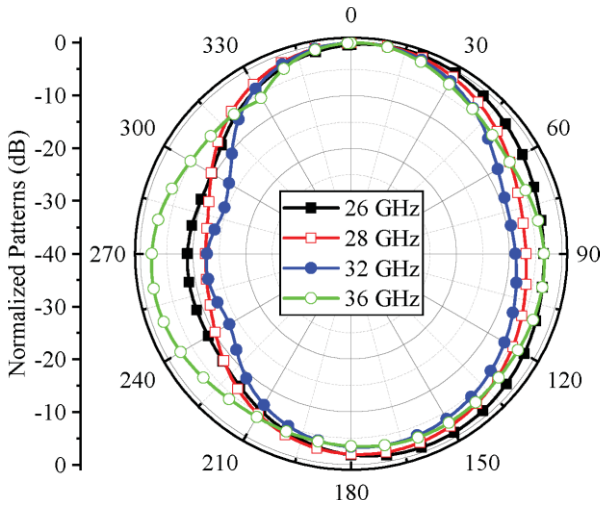
Figures 6(a) and (b) show the simulated radiation characteristics for the xz-plane ($\varphi = 0^\circ$) and the yz-plane ($\varphi = 90^\circ$). The radiation patterns are plotted at four different frequencies, such as 26 GHz, 28 GHz, 32 GHz, and 36 GHz. From the results of Fig. 3, it can clearly be observed that the antenna has a monopole-like radiation pattern for both the planes. In the case of yz-plane, the patterns are titled towards $\pm 30^\circ$. This kind of behavior indicates that the designed antenna is able to provide wide radiation coverage.

IV. Conclusion

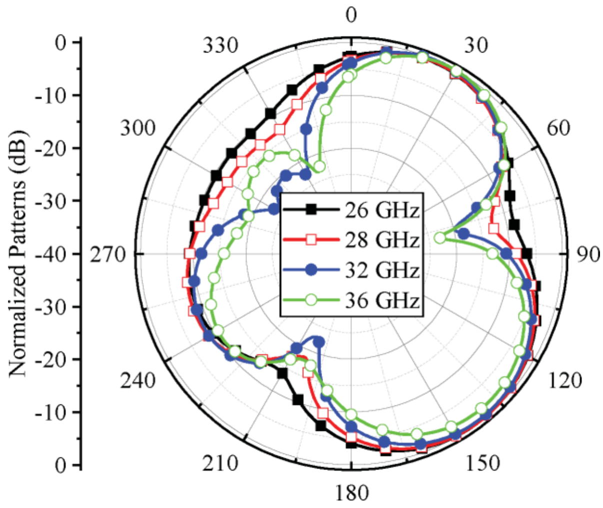
This paper presents the design of a wideband antenna for mm-wave applications. The proposed antenna consists of an equilateral triangle slot-based rectangular resonator backed by a partial ground plane. The simulated results show that the impedance bandwidth of 16.86 GHz is with an antenna efficiency and peak gain of >85% and 6.86 dBi, respectively.

Acknowledgment

Mohammad Alibakhshikenari and Farhad Arpanaei acknowledge support from the CONEX-Plus programme funded by Universidad Carlos III de Madrid and the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No. 801538.



(a)



(b)

Fig. 6. Radiation characteristics of the proposed mm-wave antenna for (a) xz-plane and (b) yz-plane.

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