A High-Gain Dual-Band Slotted Microstrip Patch Antenna For 5G Cellular Mobile Phones

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ABSTRACT

Microstrip patch antennas have been widely used in contemporary mobile communication technology, including 5G. Previous studies in the area have shown that such antennas can be optimized to operate in different bands of 5G. This study proposes a microstrip patch antenna designed to operate at 26 and 28 GHz and aimed at improving the gain and other radiation characteristics by adding a combination of different slot shapes to a single rectangular patch that is very common and popular in 5G antennas. The results show that the gain is noticeably increased by inserting two hammer slots and a rectangular slot in the middle between them. The dimensions of the slots are optimized using the CST Studio Suite simulator. A comparative analysis was performed to demonstrate the superiority of the proposed over previous designs in terms of gain value and other radiation parameters. The results suggest that such a very simple and low-profile antenna can be a good candidate for 5G mobile applications.

Keywords-5G mobile communications; antennas; gain; microstrip patch antenna; slots

I. INTRODUCTION

Due to their low profile, low cost, small size, easy fabrication, and conformity, microstrip patch antennas have been widely used in mobile communication systems, including mobile phones, Radio Frequency Identification (RFID), Global Positioning System (GPS), radar systems, and many others [1-6]. Such antennas have also been used efficiently in 5G wireless communication systems [6-7]. The millimeter-wave (mmWave) band forms a major part of 5G networks, ranging between 24.25-27.5, 27.5-29.5, 37-40, and 64-71 GHz [9]. In particular, the two most important operating frequency bands for millimeter waves, as defined by the Federal Communication Commission (FCC), are 26 and 28 GHz [9-10]. The availability of mmWave spectrum, especially at 26 and 28 GHz, has attracted the interest of various radio technologies, including mobile communication. Therefore, these two particular frequencies have been the subject of considerable attention by many studies in 5G technology [9-14]. Many studies have been conducted to improve the radiation characteristics of microstrip patch antennas for 5G systems. A major drawback of microstrip antennas is their narrow bandwidth, which can be increased by slotted patches, thick substrates, low effective permittivity substrates, multiple resonance integration, and impedance matching optimization [16-18]. In addition, the use of mmWaves has some issues related to high path loss, atmospheric and rain absorption susceptibility, and shadowing by materials as well as the human body, which can all be overcome by employing antennas that exhibit high gain and wide bandwidth [19]. However, in 5G, the narrow bandwidth may not be a key issue as in other wireless systems operating in lower frequency bands [20]. The most important issue is the gain, which must be dramatically increased to meet the fast and reliable communication requirements, as long as the bandwidth remains wide enough to accommodate the large amounts of data intended to be transmitted [21]. This study aims to improve the gain of a microstrip patch antenna operating in the 26 and 28 GHz bands (Ka-band).

In [22], a compact planar inset-fed microstrip antenna was proposed for 28 GHz, shown to provide a gain of 6.83 dBi. In [8], a triple band antenna with low relative permittivity and small thickness substrate was designed to operate at 24.4, 28, and 38 GHz. The gain achieved at these frequencies was 6.65, 7.02, and 5.05 dBi, respectively. In [23], a dual-band Coplanar Waveguide (CPW) slot directive antenna was designed to operate at 28 and 38 GHz for 5G. The maximum gain achieved for the two bands was 6.6 and 5.6 dBi, respectively. In [24], a broadband elliptical-shaped slot antenna was designed to cover the 5G band from 20 to 40 GHz, with a maximum gain of 5 dBi. In [25], a dual-band Planar Inverted-F Antenna (PIFA) was designed with a CPW feeding line. This antenna achieved a bandwidth of 3.34 GHz and 1.395 GHz and a gain of 3.75 and 5.06 dBi in the 28 and 38 GHz bands, respectively. In [26], a combined structure using a microstrip patch radiator and a waveguide aperture was developed to provide a wide beam and high gain in a particular tilted direction. The maximum gain achieved at 28 GHz was 7.41 dBi. A slotted microstrip patch antenna was presented in [27] to operate at 28 GHz for 5G applications. This design was based on using two different shaped slots placed in the middle of the patch and connected through a narrow short strip. This compact antenna design was shown to provide a gain of 6.37 dBi. In [28], a dual-band (28 and 45 GHz) elliptical-slotted circular patch antenna was proposed for 5G communication, providing the maximum gain of 7.6 dBi at 28 GHz. In [29], the Defected Ground Structure (DGS) and the stub slot configuration were used to design a dual-band (28 and 45 GHz) microstrip patch antenna with a wide bandwidth and high gain. The maximum gain achieved was 8.31 dBi. In [28-29], microstrip patch antennas were optimized to operate at 28 GHz for 5G, achieving a gain of 7.43 and 9.82 dBi, respectively.

Many studies focused on using microstrip patch arrays to enhance beamforming and directivity, hence the gain of microstrip patch antennas for 5G applications [13, 15, 17, 30-42]. These studies showed that some array structures resulted in gains that exceeded 10 dBi. However, since patch arrays significantly increase design complexity and total antenna size, such designs may not be the best option when it comes to simplicity in many circumstances. Unlike other studies, this one presents the design of a very simple dual-band microstrip antenna operating at the 26 and 28 GHz mmWave bands of 5G. This study uses the slotted patch method to increase the antenna gain and directivity along with other radiation characteristics, such as return loss, Voltage Standing Wave Ratio (VSWR), and efficiency, without compromising the impedance bandwidth too much.

II. ANTENNA DESIGN

Considering that rectangular patch antennas are widely used over other structures [43-45], the proposed antenna is based on a rectangular patch slotted with two identical hammer slots and a single rectangular slot placed between them. The substrate used was a Rogers RT5880 having the following dimensions: 20 mm length, 16.5 mm width, and 0.508 mm thickness. The relative dielectric permittivity (ε_r) is 2.2, and the tangential loss (tan δ) is 0.0009 [46]. Among the various feeding techniques available for microstrip patch antennas, the inset feed technique was selected to achieve a great impedance matching between the feed line and the patch. The patch dimensions are 9.9×9.7 mm^2, which is fed by a 50 Ω microstrip line with a width of 0.7 mm and a length of 4.75 mm. Table I provides the optimized dimensions of the proposed hammer-slotted patch antenna shown in Figure 1. The dimensions L1, W1, L2, W2, L3, and W3 are the optimal dimensions obtained from a parametric analysis using the sweep option provided by the CST Studio Suite simulator.

TABLE I. OPTIMAL DIMENSIONS OF THE HAMMER-SLOTTED PATCH ANTENNA

Dimension	L1	W1	L2	W2	L3	W3
Value (mm)	1	1.5	5.3	0.5	3.5	4

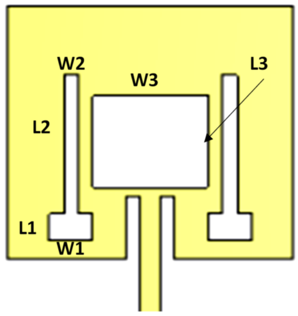

Fig. 1. Geometrical representation of the hammer-slotted patch antenna.

III. RESULTS

The proposed hammer-slotted patch antenna was simulated using the CST simulation software. Table II shows the simulation results in terms of resonance frequency, return loss, VSWR, bandwidth, gain, directivity, and efficiency. The results clearly show that S11 at the 26 and 28 GHz frequency bands was -16.17 and -15.95 dB, respectively. The gain achieved was 8.678 and 10.62 dBi for the 26 and 28 GHz bands, respectively, which is comparatively very high. The directivity was equal to 8.972 dB at 26 GHz and 11.22 dB at 28 GHz. On the other hand, the VSWR in the two frequency bands was equal and close to 1, meaning that a very good matching was achieved between the feeding system and the antenna. Similarly, the antenna efficiency was very high, approximately 96 and 95 % at the 26 and 28 GHz bands, respectively.

TABLE II. SIMULATION RESULTS OF THE PROPOSED ANTENNA AT 26 AND 28 GHZ

Frequency (GHz)	S11 (dB)	VSWR	BW (GHz)	Gain (dBi)	Directivity (dB)	Efficiency %
26.21	-16.17	1.37	0.506	8.678	8.972	96.8%
27.78	-15.95	1.37	0.72	10.62	11.22	94.65%

TABLE III. COMPARISONS OF THE PROPOSED AND PREVIOUS ANTENNAS AT THE 28 GHZ BAND

Design	Center Frequency (GHz)	Minimum S11 (dB)	VSWR	BW (GHz)	Gain (dBi)	Directivity (dBi)	Efficiency %	Other 5G Bands (GHz)
Hammer-slotted design	27.78	-15.95	1.37	0.72	**10.62**	**11.22**	94.65%	**26.21**
[31]	28.1	-42	**1**	1.29	9.82	-	**99.99%**	-
[29]	**28**	**-54**	**1**	**5.13**	8.31	8.35	98%	38.5
[28]	**28**	-40	1.01	1.3	7.6	7.68	85.6%	45
[26]	**28**	-35	-	1.5	7.41	-	-	-
[8]	28.1	-19.3	1.244	0.9	7.02	7.69	85.5%	24.4, 38
[22]	28.06	-18.25	1.278	1.1	6.83	-	-	-
[27]	28	-40	1.022	2.48	6.37	6.99	86.73%	-

The bandwidth of the proposed antenna at the two bands, equal to 0.5 and 0.7 GHz, respectively, is considered acceptable for many 5G applications. Such a modest bandwidth is outweighed by the very high gain obtained. As noted earlier, gain has a higher priority than bandwidth in the development of 5G antennas in many cases, as long as the bandwidth is maintained wide enough to cover 5G services. Table III shows a comparison between the results of the proposed antenna and previous studies. Figure 2 shows the S11 parameter in dB with respect to the operating frequency. Figures 3 and 4 show the radiation patterns of the hammer-slotted antenna at both resonance frequencies.

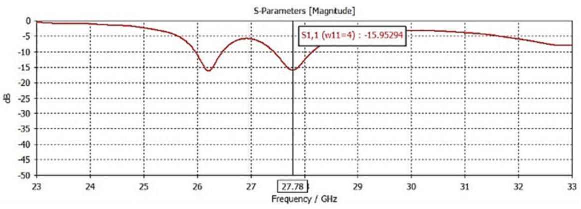

Fig. 2. S11 as a function of frequency for the proposed antenna.

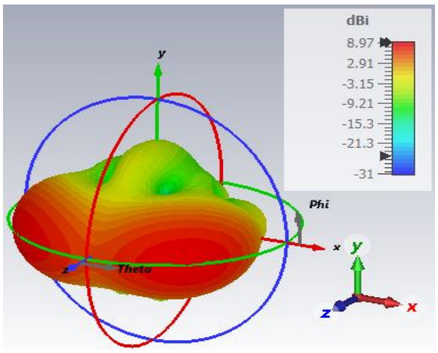

Fig. 3. The radiation pattern for the hammer-slotted antenna at 26 GHz.

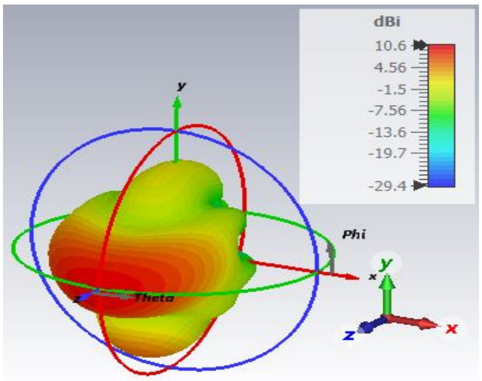

Fig. 4. The radiation pattern for the hammer-slotted antenna at 28 GHz.

IV. COMPARISON OF THE HAMMER-SLOTTED ANTENNA WITH OTHER DESIGNS

Table III provides a detailed comparison between the proposed hammer-slotted antenna and a set of other designs, all using a single patch structure and a resonance frequency of 28 GHz. Note that all studies on the 26 GHz band found in the literature were either based on antenna arrays or were not designed for the Ka-band considered in this study. This paper does not provide a comparison for 26 GHz antenna designs. The results in Table III are sorted in descending order according to gain. In addition, the best result values obtained for all parameters are deliberately highlighted to facilitate comparison between the proposed and alternative designs. When analyzing the results shown in Table III, it is clear that the proposed hammer-slotted antenna provided the highest gain and directivity. However, other parameters have not been compromised compared to the competitive designs outlined in the table, except for bandwidth. The bandwidth here was compromised (compensated for) by the significantly increased gain and directivity values while maintaining a very simple antenna structure. This indicates that the proposed microstrip patch antenna can be a good candidate for 5G cellular mobile phones when simplicity, cost-effectiveness, and reduced antenna size are required.

V. DISCUSSION

The proposed rectangular slotted microstrip patch antenna design for 5G applications operating at 26 and 28 GHz demonstrated significant improvements in gain, directivity, return loss, VSWR, and efficiency. The use of hammer-slot shapes in a single patch structure allowed for enhanced radiation characteristics without sacrificing impedance bandwidth. The results obtained outperformed previous designs, positioning this antenna as a promising option for 5G cellular mobile phones. The simplicity, low profile, and lightweight nature of this antenna design further contribute to its suitability for practical applications. The novelty of this work lies in the optimization of a dual-band microstrip antenna for the 26 and 28 GHz mmWave bands, addressing the need for high-gain solutions in 5G mobile applications. By focusing on a single patch structure with specific slot configurations, this design offers a balance between performance and complexity.

Comparison with other antenna designs further underscores the competitive advantage of the proposed one in terms of key parameters such as gain and directivity. The knowledge gap addressed by this study pertains to the lack of simple yet high-performing antenna designs specifically tailored for the 26 and 28 GHz frequency bands in the existing literature. By providing a detailed analysis of the simulation results and performance metrics, this study contributes valuable insights into the field of antenna engineering for 5G applications. Compared to other studies focusing on antenna arrays or different frequency bands, the proposed design stands out for its single-patch structure and optimized radiation characteristics. In general, this study underscores the importance of innovative antenna design strategies in advancing the capabilities of 5G communication systems.

VI. CONCLUSION

This study introduced a rectangular slotted microstrip patch antenna to meet the requirements of high-band 5G mobile applications. The main objective was to improve antenna gain and directivity, as well as other key radiation characteristics such as return loss, VSWR, and efficiency. The proposed antenna design consisted of a single patch for simplicity purposes (not an array of patches) and aimed to operate in the

26 and 28 GHz 5G frequency bands. Choosing hummer-slot shapes, the antenna consisting of two symmetric hammer slots along with a single rectangular slot placed in the middle, with optimized dimensions, has been shown to provide very good radiation properties, particularly in gain and directivity. The antenna gain for the two chosen frequencies was equal to 8.678 and 10.62 dBi, respectively, which were shown to be higher than those achieved in previous studies. The directivity values for these two bands were 8.972 and 11.22 dB, respectively, and the minimum return loss obtained in both bands was almost -16 dB. This S11 value was still some way below the -10 dB return loss. The bandwidths of the two bands at -10 dB return loss were equal to 0.506 and 0.72 GHz, respectively, with a total bandwidth of 1.226 GHz covering the 5G spectrum lying between 25 and 29 GHz. In addition, the VSWR at both bands was 1.37, and the efficiency was 96.8 and 94.65% for the 26 and 28 GHz bands, respectively.

The results obtained in this study were very good and satisfactory compared to those reported in the literature. Based on these results and the fact that it is low profile, lightweight, and relatively simple, the proposed microstrip patch antenna can be an appropriate design option for 5G cellular mobile phones. Future work suggests studying the impact of using other slot combinations, other substrate designs, or possibly employing antenna arrays to provide enhanced values of gain, efficiency, bandwidth, and all other radiation parameters.

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