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Original Article

A Modified Ground for Bandwidth Enhancement of the Microstrip Patch Antenna for 5G Wireless Communications

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Abstract *- Since the antenna is the most critical component in wireless communications, as it is used to send and receive electromagnetic waves, therefore its design process must be compatible with the application in which it is used. Because of the high demand for data transfer and the use of millimeter-wave (mm-wave) to solve this problem, the antenna must be small since these waves have high frequencies. The best type for this purpose is Microstrip Patch Antennas (MPAs). This work proposes an MPA with a single band and modified ground for 5G communications. The small antenna with an inset feed line and modified ground plane gives a single band at 47.2 GHz with a wide bandwidth of about 2.8 GHz and a return loss of about -24.71 dB with a gain of 4.7 dB. HFSS software is utilized for both the simulation and antenna design. The simulation's findings indicate that the antenna is appropriate for 5G applications.*

Keywords *- Microstrip Patch Antenna, Bandwidth enhancement, Modified ground, mm-wave applications, 5G applications.*

1. Introduction

Innovative applications in wireless communications systems are well-suited to and attracted to the Ka-band frequency of the mm-wave spectrum. The antenna must be built with specific features to get the desired outcomes for these systems, such as more bandwidth and better gain. The International Telecommunications Union (ITU) revealed the possible mm-wave frequency range between 24 GHz and 84 GHz during a World Radio Communication Conference in 2015.

An antenna is a vital part of the telecommunications sector. It functions as a transducer, converting electrical energy into radio and radio signals into electrical energy. Through wireless communication technology, individuals residing in geographically distant areas may connect by sending and receiving signals. MPA is well-liked for its low volume, low cost, and low profile and is used in many different applications [1].

Simultaneously, it has been imperative to address the operational issues with microstrip antennas, such as low gain, restricted bandwidth, and decreasing efficiency, to enhance the effectiveness of the MPA [2]. Most past research on this topic indicates that, depending on the application, the MPA's shape and substrate properties significantly influence how well the antenna operates and is used [3]. In comparison to a standard microstrip patch, it has been reported in previous studies that C-shaped patch antennas can achieve a reduction in size of around 67% [4], and 37% [5].

Many applications need a single band with a high data transfer bandwidth and a miniature antenna size. A 28 GHz single-band MPA for mobile 5G communications with a gain of about 7.587 dB and bandwidth of about 1.046 GHz was presented in [6]. Hence, the paper proposed a novel method to increase the bandwidth, decrease the VSWR, and improve the efficiency of MPA.

A broadband MPA for 5G communications with a bandwidth of about 2.5 GHz was proposed in [7]. In [8], a single-band MPA was presented with a bandwidth of about 2.05 GHz and a stable gain of about 6.32 dB. A 28 GHz U-slot MPA for 5G communications with an increase of about 4.06 dB using a coaxial cable feed was proposed in [9].

The current work presents an MPA with modified ground for 5G applications. A single band with a broad bandwidth of about 2.8 GHz and a gain of 4.1 dB was proposed. To enhance the bandwidth, we used a modified ground-in antenna structure. The HFSS program was used to carry out the simulated investigations. The main contribution of our study is we use the findings of our simulation to highlight the effect of ground plane form on bandwidth.

The rest of this study is organized as follows: The antenna construction and theoretical concerns were explained in section 2. Section 3 describes the simulation results. In the final section, Section 4, the overall study results, advice, and ideas for further research are made clear.

2. MPA Design

The MPA's primary constituents are the substrate, ground, patch, and feed line. A dielectric produces the substrate, while the other planes are made from a conductive substance.

MPA is utilized in mm-wave, microwave, and cellular communications. It comes in various forms: ring, square, circular, rectangular, and elliptical. Figure 1 shows the proposed wideband MPA structure when the ground plane is modified, which comprises a substrate, ground plane, and radiator patch (Figure 1(b)).

FR4 epoxy with a thickness of 0.158mm and a dielectric constant of ϵ_r = 4.4 is used to make the substrate. The inset feed line with a 50 ohm impedance fed the antenna. The parameters in this study were calculated using the formulas found in [2].

W_{Patch} :

$$W_{Patch} = \frac{c}{2f\sqrt{\frac{\epsilon_r + 1}{2}}}$$

L_{Patch} :

$$L_{Patch} = L_{eff} - 2\Delta L$$

$$L_{eff} = \frac{c}{2f\sqrt{\epsilon_{eff}}}$$

$$\Delta L = 0.412\frac{(\frac{W_{Patch}}{H_{Substrate}} + 0.246)(\epsilon_{eff} + 0.3)}{(\epsilon_{eff} + 0.258)(\frac{W_{Patch}}{H_{Substrate}} + 0.813)}$$

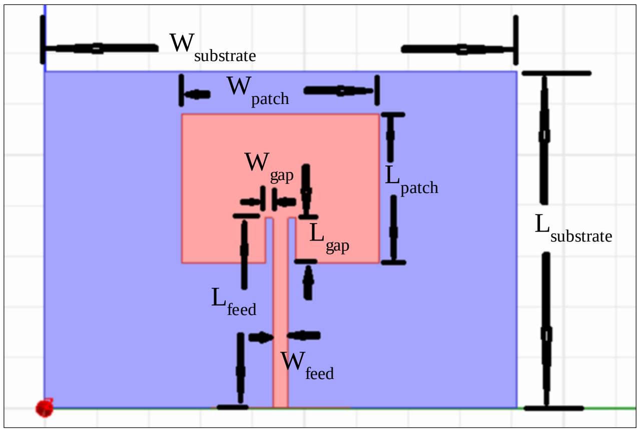
$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}(1 + 12\frac{H_{Substrate}}{W_{Patch}})^{\frac{-1}{2}}$$

W_{Feed} : The 50Ω inset feed transmission feedline was connected to the recommended antenna since additional matching components are not required in this manner. The transmission feedline width is calculated using the following formula,

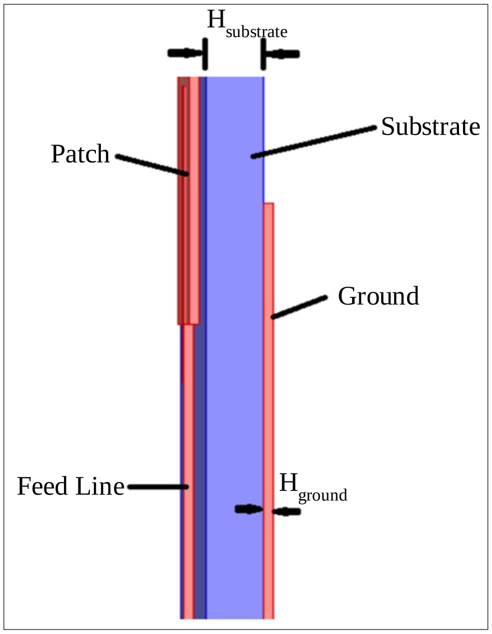
$$W_{Feed} = \frac{7.48 H_{Substrate}}{e^{(50\frac{\sqrt{\epsilon_r + 1.41}}{87})}}$$

Table 1. Parameters of the suggested antenna in mm units

Parameter Symbol	Value
$W_{substrate}$	6.7
$L_{substrate}$	9.1
$H_{substrate}$	0.2
W_{ground}	6.7
L_{ground}	4.55
H_{ground}	0.035
W_{patch}	3.8
L_{patch}	2.95
W_{feed}	0.3
L_{feed}	2.9
W_{gap}	0.2
L_{gap}	0.9



(a) Top view



(b) Side view

Fig. 1 The structure of the proposed antenna

3. Results and Discussion

We provide a small antenna for 5G wireless communications in this work. The size of a ground plane affects an antenna's performance, which includes efficiency, gain, and radiation pattern. The ground plane's small size has less of an effect on frequency, although it does cause a drop in the front-to-back ratio. The enormous ground plane has little impact on the gain since it will expand. The frequency is controlled by the patch length, which is about λ/2 of the rectangular patch. Initially, the recommended antenna was adjusted to produce the required characteristics. HFSS software was utilized to conduct the simulation studies and recommend an antenna design.

3.1. The Results of Return Loss and Bandwidth

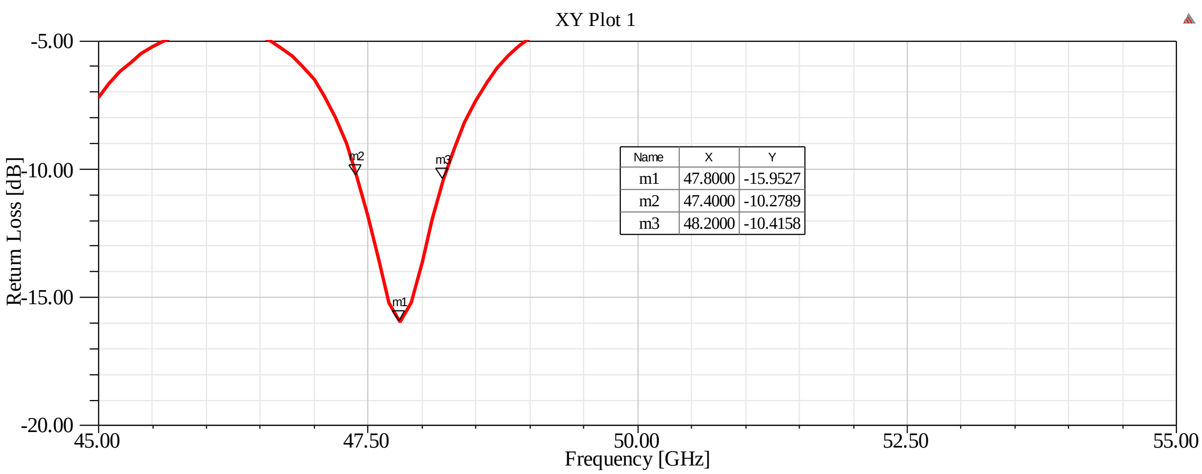
Since only 10% of the power is reflected by the antenna during wireless or mobile communication, the base value for return loss is determined to be -10 dB. Figure 2 illustrates the antenna's performance, Figure 2(a) shows the antenna performance with the entire ground plane as the exact dimensions of the substrate. The y-axis denotes the return loss in dB, and the frequency in GHz is on the x-axis, and it appears a single band at frequency 47.8 GHz with -15.95 dB return loss and bandwidth of about 0.8 GHz with VSWR less than 2. Figure 2(b) denotes the antenna performance with modified ground, and it appears as a single band at a frequency of 47.2 GHz with -24.7 dB return loss and an overall bandwidth of about 2.8 GHz with VSWR less than 2.

3.2. The Results of VSWR

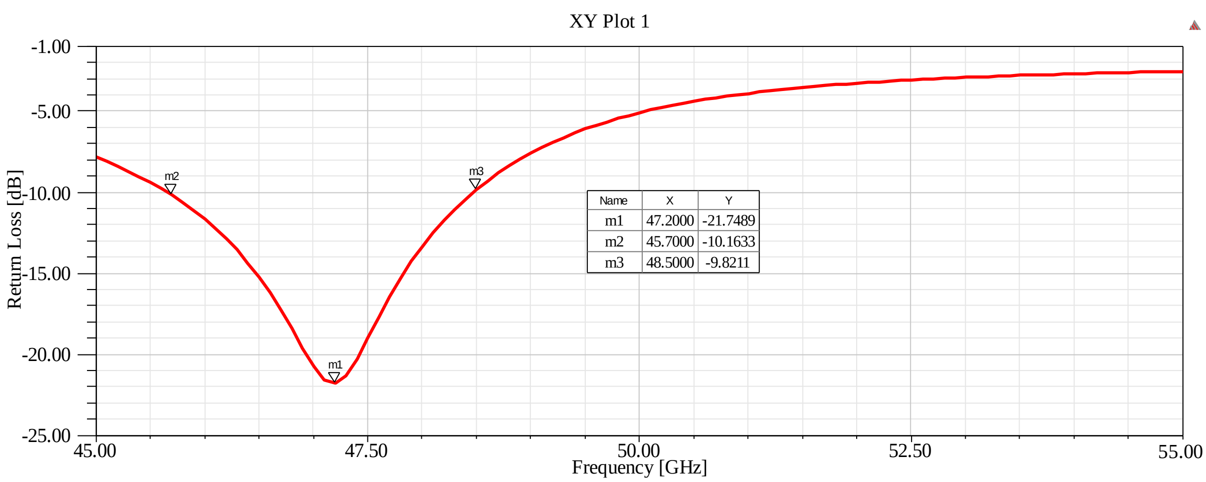
Any patch antenna should have a maximum VSWR of two along the efficiency bandwidth, ideally one. Figure 3 illustrates that the antenna shows a 1.0118 dB at 47.2 GHz, where the y-axis denotes the VSWR values in dB, and the x-axis indicates the frequency in GHz.

3.3. The Results of the Current Surface Distribution

To better understand the electromagnetic radiation pattern for bands, we addressed the present surface distribution for the suggested antenna at the operating frequency. At 47.2 GHz, the feed line and the borders of the lower patch showed a significant surface current density, as seen in Figure 4.



(a) With the full ground plane



(b) With the modified ground plane

Fig. 2 The performance of the antenna

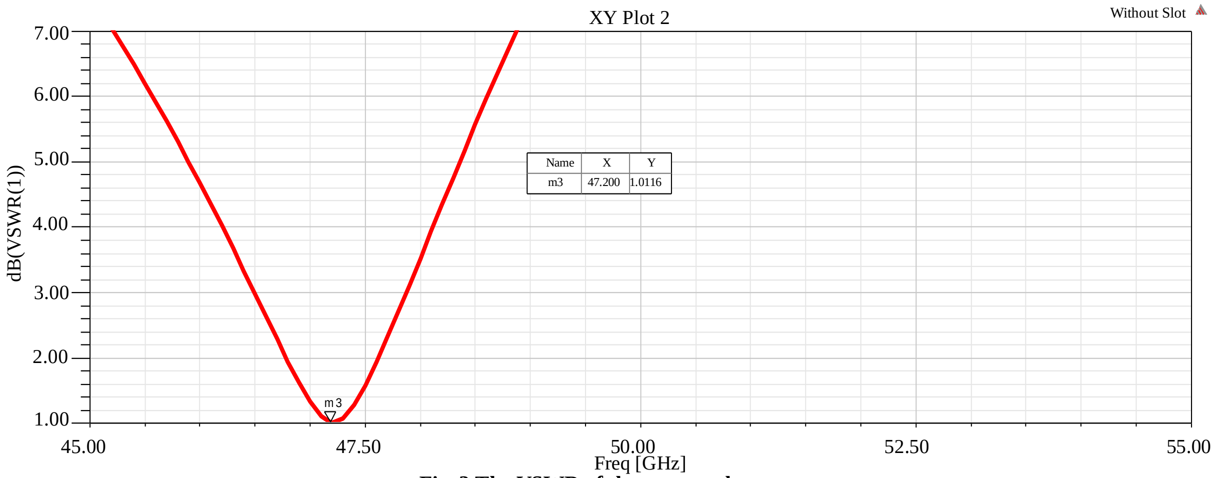


Fig. 3 The VSWR of the presented antenna

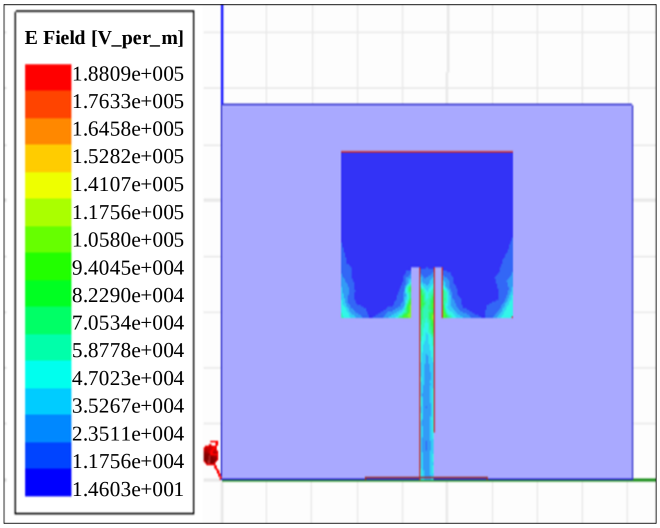


Fig. 4 The proposed antenna current surface

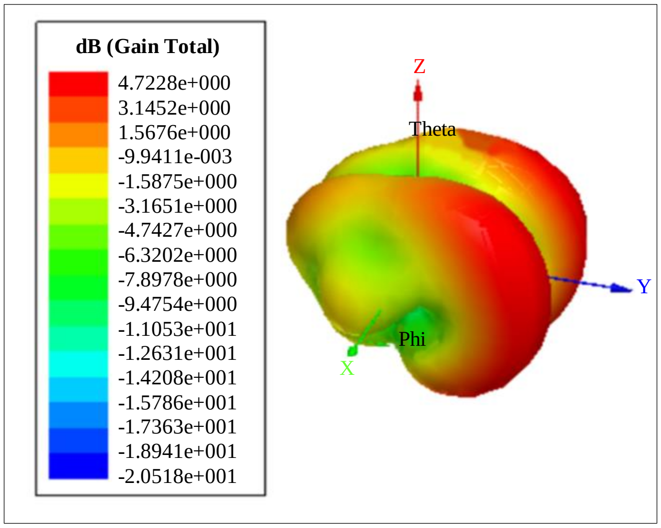


Fig. 5 The presented antenna gain

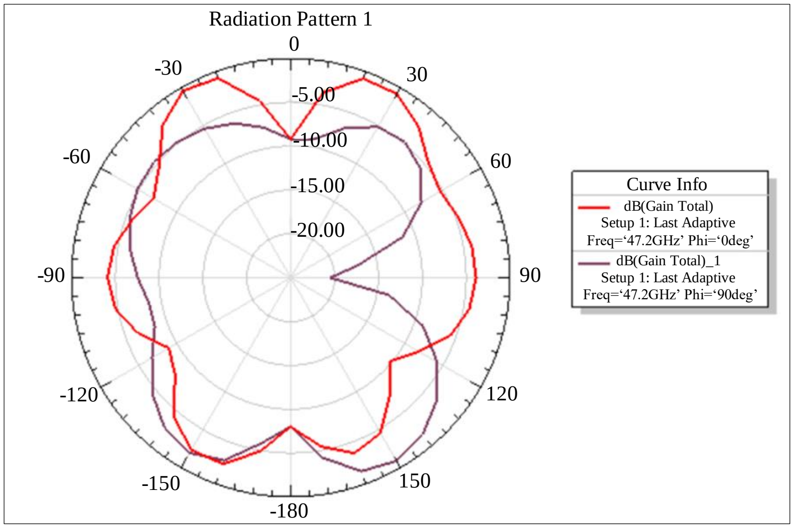


Fig. 6 The proposed antenna radiation pattern

Table 2. Antennas of previous research compared with the current work provided

Ref. No.	Size of Antenna (mm)	Return Loss (dB)	Operating Frequency (GHz)	Bandwidth (GHz)	Gain (dB)	Slot Type
[7]	8.4×6.8×1.6	-31	28	2.5	-	Rectangle
[8]	10×10×1.6	-15.85	24.5	2.05	6.32	Rectangle
[9]	15.8×13.1×1.57	-20	28	-	4.06	U Shape
[10]	14.71 × 7.9 × 0.254	-12.59	28	0.582	6.69	Without
[11]	6.285 × 7.235 × 0.5	-13.48	28	0.847	6.63	Without
This Work	9.1×6.7×0.2	-24.71	47	2.8	4.7	Without

3.4. The Results of the Gain and Radiation Pattern

The substrate thickness and the relative dielectric constant influence the antenna gain; since the antenna gain is directly proportional to the antenna's thickness and inversely proportional to the relative dielectric constant, the MPA's gain might be improved.

The 3D plot of the antenna gain that is being given is shown in Figure 5. According to the figure, the increase is 4.7 dB at 47.2 GHz. An essential element that shows the overall performance of the antenna is the radiation pattern feature.

The suggested antenna radiation pattern for the 47.2 GHz frequency is shown in Figure 6. The figure shows that the E and H planes are almost omnidirectional. The simulation results for the suggested antenna with earlier research are reviewed in Table 2.

4. Conclusion

The current work presents an MPA with a single band and modified ground for mm-wave communications. The antenna's performance is enhanced with a bandwidth of about 2.8 GHz for the frequency 47.2 GHz with a return loss of about -24.7 dB and gain of about 4.7 dB. The small structure of the antenna makes it integrate into any device in a small space. The antenna results showed that the ground plane's size affects the antenna's bandwidth. The proposed antenna is suitable for 5G communications.

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