A Microstrip Patch Antenna with Enhanced Bandwidth for Millimeter Wave 5G Application

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Abstract. The cellular network of 5G works in the centimeter wave (3-30 GHz) and Millimeter-wave (30-300GHz). Here worldwide a vast amount bandwidth remains unused. A new microstrip antenna of dimension 10 × 10 × 1.6 mm³ has been designed and simulated using HFSS for Millimeter wave (MMW) applications, in this paper. The proposed antenna shows wide bandwidth, stable radiation patterns, and enhanced reflection coefficient at 24.5 GHz for possible 5G use. It shows impedance bandwidth of 2.05GHz(23-26 GHz) with a maximum gain of 6.32 dBi.

1. Introduction

Following the fourth generation (4G) global commercial success of mobile communications centered on the Long Term Evolution (LTE), the industry and the research community have gradually been discussing 5G mobile communications in the International Telecommunications Union (ITU). 5G pioneers launched a new mobile performance level with ultra-high speeds and low latencies. What makes that possible is the spectrum of the millimeter-wave. As with previous generations, 5G is spectrum dependent in many different bands. Fifth-generation (5G) cellular networks are designed to utilize the upper centimeter wave (cm Wave) and mm-Wave frequency bands (3-300GHz) which contain a major spectrum of frequencies usable for high data rate communication in the range of multi-gigabit per second. This high data rate is a requirement of mobile and backhaul applications. [1-2].

The telecommunications sector has now taken a major step towards meeting the dictates of the modern community and industry. Microstrip antennas are important components to generate EM waves in wireless communication systems [3]. Future wireless 5G communication networks are also likely to use MMW frequencies, namely 24GHz, 28 GHz, 38GHz, 60GHz, and 70GHz [4]. These frequency range of bands are utilized by the 5G mobile network. The experimental test demonstrates that the atmospheric absorption at 28GHz and 38GHz is less about 200 meters, whereas attenuations are low between 70GHz and 100GHz and between 125GHz and 140GHz frequencies. Also the Federal Communications Commission (FCC), has suggested that the 28 GHz (27.5 GHz – 28.35 GHz) band will be approved for mobile operations. However, that band is not ample for 5G applications. [5-10].

For subscribers to continue to increase their desire for improved mobile broadband service, critical
changes inefficiency such as

i. Much better throughput for Ultra-HD video and VR applications, with data rates of 1 Gbps or more.

ii. Latency lesser than 1milli second, for Device to Device (D2D) mobile applications in real-time.

iii. Extremely reliable and good connectivity to provide seamless services everywhere.

In addition, it should be noted that the radiation output of the 5G millimeter wave antenna is superior to that of its predecessors viz., the 2G, 3G, and 4G with regard to radiation, power, adaptivity, new bandwidth and the efficiency of the radiation. [11-13]

This proposed work deals with a resonance frequency of 24.5GHz for 5G applications, which includes a new microstrip patch antenna design with a broad bandwidth, a relatively standard gain and a small sized antenna. The antenna proposed was imprinted on a type FR4 substrate and fed with a microstrip line. The main principle of our article is to increase the bandwidth of the antenna while retaining its smaller size and relative high gain at the same frequency of the 24.5GHz.

Two design steps were suggested and presented for this purpose: the first step deals with the design of the basic elements of the proposed geometric shape in the absence of the slots. The second step is related to changes in the geometry of the basic structure, which is done by inserting each timeslots to accomplish the desired goals with regards to adaptation, bandwidth, gain, and size to a 24.5 GHz resonance rate. The proposed 5G mmW antenna has a broad bandwidth, a relatively high gain and a smaller size compared to other 5G antennas [12-17]. The benefits of the proposed antenna include:

i. Simple setup

ii. Wide bandwidth operation

iii. Steady radiation pattern

iv. Significant gain.

2. The calculation for microstrip patch antenna

Microstrip patch antennas have many advantages such as light weight, low cost and volume, low profile, compact size and ease of manufacture and conformity which makes it suitable for designing purpose and hence it is more versatile than other conventional antennas [18]. It can easily be integrated with electronic circuits such as LNA (Low-Noise-Amp) and SSPA (Solid-State Power Amplifier) [19]. Majority of the models categorize microstrip antennas result in time-consuming computing. The first model for the rectangular antenna research was based on magnetic current distribution in the antenna [20].

Based on the proposed work, antenna parameters are calculated [18]. The first part is to calculate the antenna’s length (m1) and width (m2) using the following formula:

\[ m2 = \left( \frac{c}{2f_0} \sqrt{\frac{2}{\varepsilon_r+1}} \right) \]  \hspace{1cm} (1)

where \( c \) the speed of light is, \( f_0 \) is the resonance frequency and \( \varepsilon_r \) is the dielectric constant.

The effective dielectric constant is given by

\[ \varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[ 1 + \frac{12h}{m2} \right]^{\frac{1}{2}} \]  \hspace{1cm} (2)

where \( h \) is the thickness/height of the substrate
The effective height is given by

\[ m_{1_{\text{eff}}} = \frac{c}{2f_0 \sqrt{\varepsilon_{\text{eff}}}} \]  

(3)

The extension of height is given by

\[ \Delta m_1 = 0.41 h \left[ \frac{(\varepsilon_{\text{eff}} + 0.3) \left( \frac{m_2}{h} + 0.264 \right)}{(\varepsilon_{\text{eff}} - 0.258) \left( \frac{m_2}{h} + 0.8 \right)} \right]. \]  

(4)

The height of the patch is given by

\[ m_1 = m_{1_{\text{eff}}} - 2m_1. \]  

(5)

The ground plane’s width is measured by

\[ W_g = 6h + m_2. \]  

(6)

The height of the ground plane is given by

\[ L_g = 6h + m_1. \]  

(7)

Therefore, according to the above-mentioned formulas, the theoretical calculations of the width and length of the patch along with the measurements of the ground plane are done.

3. Design and analysis of proposed antenna element

The proposed antenna has a rectangular patch with slot printed on an inexpensive FR4 substrate with relative permittivity of 4.4, the thickness of 1.6mm, and loss tangent \( \delta = 0.0025 \). The length and width of both substrate and patch are calculated using the above formulas. The proposed antennas have a power port of 50\( \Omega \). The detailed measurement is shown in Table 1 below along with the figure 1.

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![Figure 1: Proposed antenna dimensions](image)
where
- \( m_1 \) and \( m_2 \) represent the length and width of the substrate respectively.
- \( b_1 \) and \( b_2 \) represent length and width of the patch.
- \( f_1 \) and \( f_2 \) are width and length of the feedline.
- \( r_1 \) and \( r_2 \) are the radiation box dimensions.

| Parameter | Dimensions (mm) |
|-----------|-----------------|
| \( m_1 \) | 10              |
| \( m_2 \) | 10              |
| \( b_1 \) | 5               |
| \( b_2 \) | 5               |
| \( f_1 \) | 1               |
| \( f_2 \) | 3               |
| \( r_1 \) | 20              |
| \( r_2 \) | 20              |

4. Evolution stage of the proposed microstrip patch antenna

The evolution stage is performed on this proposed antenna to understand how the antenna is evolved. For this proposed antenna evolution stage is performed in two stages. All the stages \( S_{11} \) graph is depicted in figure 4.

The first stage of the proposed antenna begins by taking an FR4 substrate of dimension 10x10 \( \text{mm}^2 \). A patch of 5x5\( \text{mm}^2 \) is printed on top of this substrate along with the feedline. A ground plane of same dimension as that of the substrate is taken and is illustrated in figure 2.

![Figure 2: First Stage of evolution stage. (a) FR4 substrate with patch along with feedline printed on it. (b) Ground plane](image-url)

In the second stage, a rectangular slot is made on the patch shown in figure 3.
5. Parametric analysis of proposed microstrip patch antenna
An analysis of the parameters is done to perceive the consequence of slot and feedline on the efficiency of antennas. The performance is mainly influenced by the width of the feedline and length and width of the slots. The slot length is taken as the inductance, and the slot distance is taken as capacitance.

5.1. Effect of the width of the feedline: The impact of the width of the feedline is observed by increasing and decreasing its width one at a time as depicted in figure 5.
5.2. Effect of \(sw_1\) and \(s_1\) of the slot
The impact of the slot on the antenna’s performance is observed by increasing and decreasing its width (\(sw_1\)) and length (\(s_1\)) one at a time. Here, firstly we increase and decrease (one at a time) the width (\(sw_1\)) of the slot by keeping its length (\(s_1\)) constant, which is shown in figure 6a. Secondly, we increase and decrease (one at a time) the length (\(s_1\)) of the slot by keeping its width (\(sw_1\)) constant, which is shown in figure 6b.

![Figure 6: Effect of slot: (a) Effect of width of the slot (\(sw_1\)) (b) Effect of length of the slot (\(s_1\))](image)

6. Results and discussion

Figure 7 shows the graph of \(S_{11}\) versus frequency of the proposed antenna which operates at 24.5 GHz. The bandwidth of this antenna is 2.05, and its fractional bandwidth is 8.36%.

![Figure 7: \(S_{11}\) versus Frequency graph of the antenna](image)

The radiation pattern of the antenna is shown below in figure 8 which has a unidirectional pattern of radiation in both E and H planes.
The 3D total gain pattern is observed as 6.31 dB at resonant frequency 24.5GHz as shown in figure 9.

The distribution of the surface current with a frequency of 24.5 GHz is shown figure 10 acquired by using the HFSS software to provide a correct overview of how the antenna works. It is obvious that the surface current is distributed at a frequency of 24.5GHz near the edge of the power line. It is found that the surface current is focused primarily on the edges of the rectangular slots inserted at the radiating element level and is more efficient than that of the power line.
7. Conclusion

In this article, a novel, compact microstrip patch antenna has been designed, modeled, and simulated for 5G applications at 24.5GHz. 24.5GHz is one of the frequencies used in the 5G spectrum under the frequency range 2(FR2) hence the name millimeter-wave (mm-Wave). For optimizing the dimensions, parametric analysis was carried out by varying different parameters. The experimental results have resulted in the antenna with a wide bandwidth of 2.05 GHz and a peak gain of 6.312dBi across the operating band. In addition, good stable radiation patterns have been attained. In conclusion, the designed antenna is easy to produce and a successful example for future 5G wireless communication systems.

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