URSI-RCRS 2024, ARIES/GEHU, Bhimtal, India, 22 - 25 October, 2024

High Gain Multiband Millimeter Wave Slotted Patch Antenna for 5G Applications

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Abstract

The paper presents a multiband millimeter wave patch antenna operating in the Frequency range 2 (24.25 GHz to 52.6 GHz) of 5G spectrum. The antenna is designed using Rogers RT Duroid substrate having dielectric permittivity 2.2 using Ansys Electronics Suite Software. The antenna design is initiated from standard patch antenna and by adding slots to it helps in providing high radiation efficiency at the operating bands. The antenna operates in 6 different frequency bands within the Frequency range 2 of 5G spectrum and provides adequate gain in the frequency of operation. This antenna can be used as a potential candidate for the development of antenna arrays or MIMO antennas.
Keywords: Electric (E) field; gain; microstrip patch; millimeter wave; slotted antenna;

1. Introduction

The requirement of fast and efficient communication is increasing day by day. The advancement in 5G and the upcoming 6G communications are trying to provide high data rates and faster connectivity. The 5G communication spectrum uses two frequency ranges for operation. The frequency range 1 (FR1) covers the frequency range from 410 MHz to 7125 MHz and is described as the sub-6 GHz or sub-7 GHz band [1]. It is mainly used by the LTE and WLAN technologies and is covered in recent years [1]. The frequency range 2 (FR2) covers the frequency range from frequencies between 24250 MHz and 52600 MHz, called the millimeter band (mmWave). The FR2 has a lot of advantages including its capability to support high speed, large capacity data transmissions [1, 2].

Antennas have a significant role in driving the technological advancements in the 5G communication systems. The main advancement in the 5G communication is the use of beamforming using array and Multiple Input Multiple Output (MIMO) antennas. The basic unit of most of these MIMO antennas is the millimeter wave (mmWave) based patch antennas [10]. In the conventional methods, based on the communication application, different types of antennas are designed like dipole antenna, monopole antenna, yagi-uda antenna, loop antenna, patch antenna, horn antenna, log periodic antenna, reflector antenna etc. [3-6]. Among these techniques, with the increase in the demand of high speed, and higher data rates, the PCB board has to be replaced with newer technologies and switching on to on board antenna designs [6]. These onboard designs require efficient high frequency planar printed antennas for high speed and efficient communication [7]. These antennas find application in smartphones, Internet of Things (IoT) modules, laptops, vehicular communications and in other devices due to its high efficiency, compact size and ease of integration [8, 9]. As these planar antennas can be directly integrated with the board, impedance matching can be assured and tested at the time of board making itself [10].

One of the basic requirements for the 5G communication in FR2 is the requirement for enhanced bandwidth and frequency tuning with improved gain and radiation efficiency. The requirement to reorient the radiation pattern is required in certain cases to reduce the radiation effects towards one side [11]. So, based on the application, the characteristics of the antenna are finalized and designed, as it has various applications as it can be even used as a sensor [12, 13]. One method to attain these characteristics is to incorporate slots onto the patch area. Thus the loss due to the surface waves can be reduced resulting in enhanced performance of the antenna.

The design, optimisation and analysis of a printed slotted planar patch antenna that could operate in the 5G frequency bands is detailed in this paper. Section 2 deals with the antenna design and Section 3 discusses the results and analysis of the designed antenna.

2. Antenna Design

The microstrip patch antenna is one of compact low profile antenna configurations used for wireless communication applications. The rectangular patch over one surface of the substrate is the key radiating element where the ground plane is on the other surface of the substrate. The design and development of antennas for the 5G application is an inevitable factor for the modeling of the communication system in the 5G frequency band. So an antenna configuration with standard microstrip patch is a novel approach for the new era of communication.

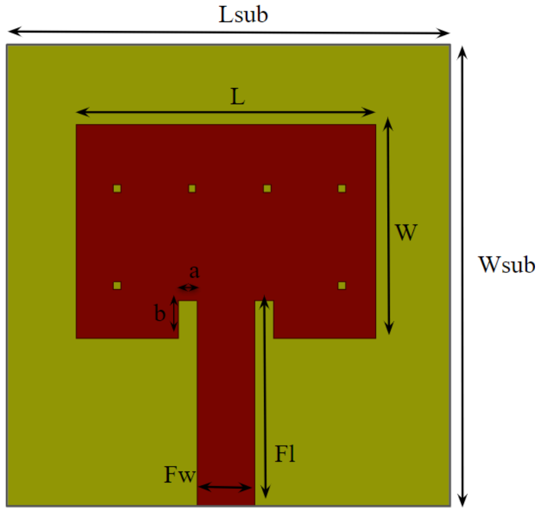


Figure 1. Slotted patch antenna

The design is initiated from a standard patch antenna [14]. The antenna is designed using RT Duroid substrate having height 0.51 mm and dielectric permittivity 2.2 and loss tangent 0.0009. The back side of the antenna is completely the ground plane. In order to obtain high gain and radiation efficiency in multiple resonating frequencies, rectangular slots were introduced onto the patch. The designed slotted patch antenna is shown in Figure 1 and the optimized dimensions of the designed antenna is given in Table 1.

Table 1: Dimensions of slotted patch antenna

Design Parameter	**Dimension (mm)**
Length of Patch, L	5.7
Width of Patch,W	8
Feed Length, Fl	5.5
Feed Width, Fw	1.54
Insert feed dimension (a x b)	0.5 x 1
Single Slot dimension	0.2 x 0.2

3. Antenna Analysis and Results

The designed antenna operates in multiple bands within the FR2 of the 5G spectrum covering the band from 24.25 GHz to 52.60 GHz. The antenna operates in five different frequency bands - 24.4 GHz, 30.2 GHz, 34.1 GHz, 45.7 GHz and 52.2 GHz. The return loss (S_{11}) characteristics of the antenna is shown in Figure 2. The return loss of five different frequency ranges with less than 10 dB indicates that the antenna is efficiently radiating at these frequencies with least reflections.

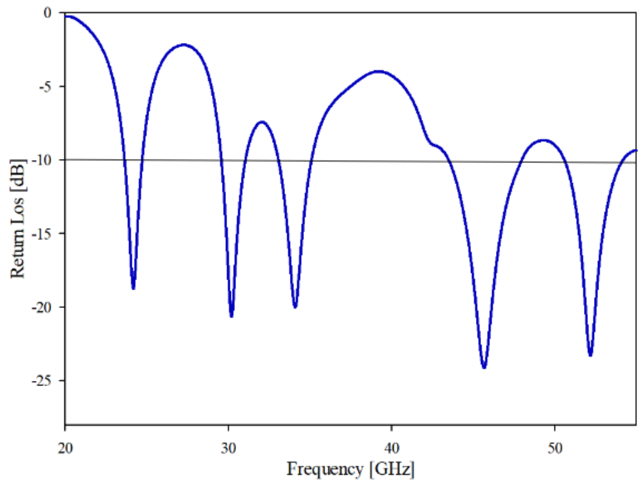


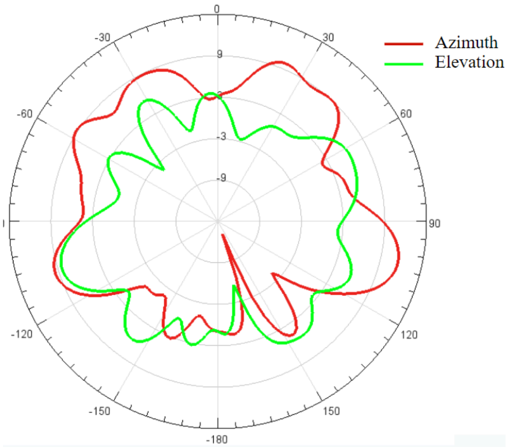
Figure 2. Return loss characteristics of slotted patch antenna

The performance of the antenna is analyzed at all the five operating frequencies. The details of return loss, bandwidth and gain at the respective operating frequencies is shown in Table 2. The performance of the antenna over the five different frequency ranges indicates that the antenna coil provides an average gain of 10 dB for the 5G applications with a better bandwidth and matching at almost all the frequencies.

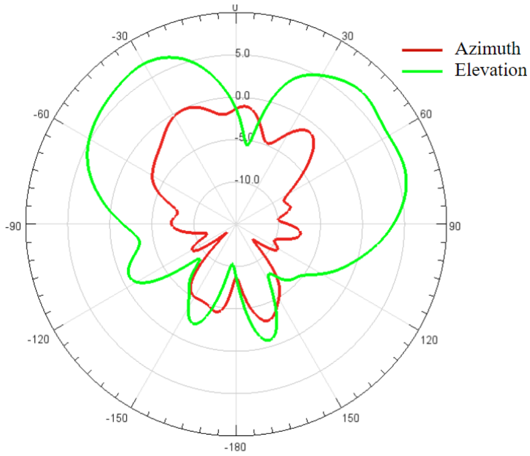
Table 2: Antenna performance

Operating frequency (GHz)	**S_{11} (dB)**	**Bandwidth (GHz)**	**Gain (dB)**
24.4	16	1.1429	13.83
30.2	21	1.3334	7.30
34.1	20	1.8095	8.65
45.7	24	3.9048	11.49
52.2	40	3.4285	13.49

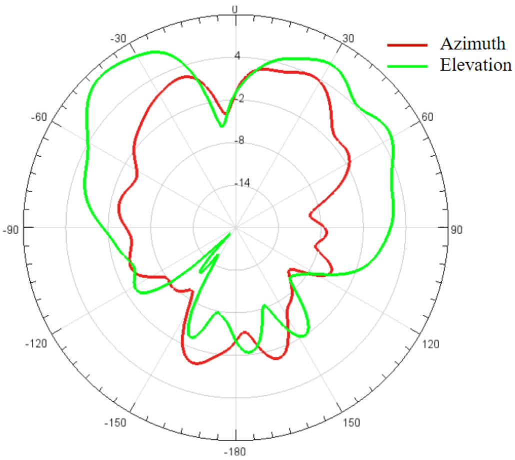
By the insertion of slots onto the patch, the current distribution over the surface of the patch increases. This helps in enhancing the radiation over the entire frequency range. The designed slots will reorient the directed radiation energy to specific sides limiting the side lobes, resulting in a directional pattern. This had helped in redistributing the current which had led to the enhancement in the gain and radiation efficiency of the designed antenna. The radiation pattern at the five operating frequency bands is shown in Figure 3.



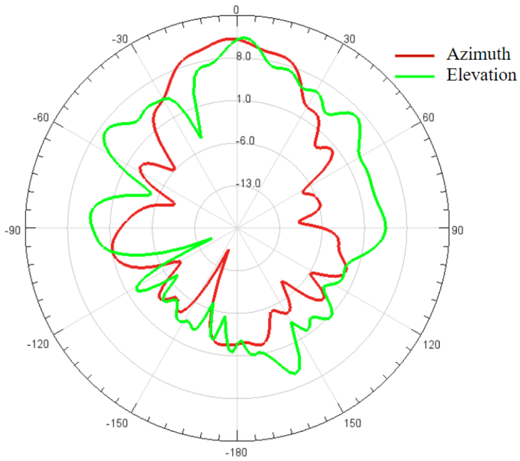
(a)



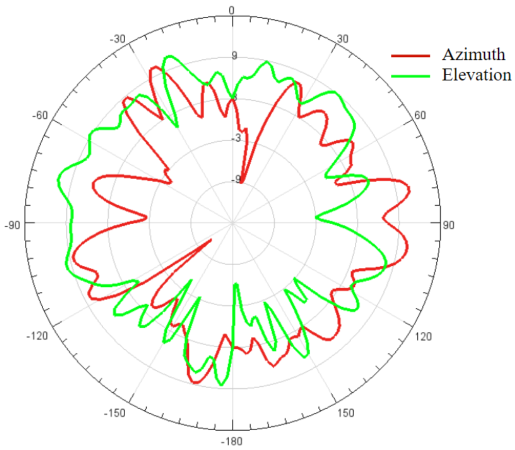
(b)



(c)



(d)



(e)

Figure 3. Radiation pattern of slotted patch antenna at frequencies: (a) 24.4 GHz (b) 30.2 GHz (c) 34.1 GHz (d) 45.7 GHz (e) 52.2 GHz

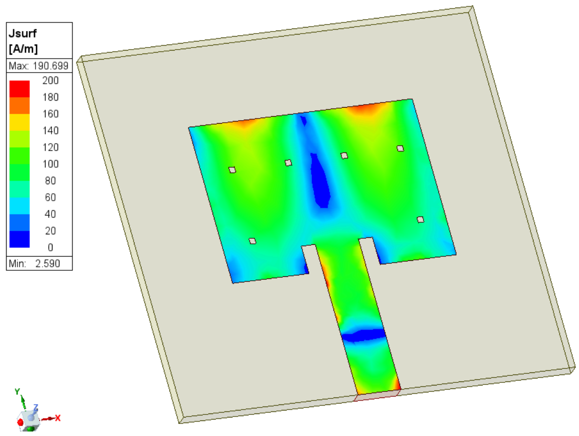


Figure 4. Surface Current Distribution

The design of slots in the patch areas had led to the suppression of surface wave losses and had resulted in the improvement of gain and radiation efficiency of the antenna. The surface current distribution of the optimized antenna at the first operating frequency is represented in Figure. 4. Adding slots on to the patch antenna had excited the additional resonant modes and had altered the electric field distribution in the patch. This had created multiple paths for current flow and made the antenna operational in multiple frequency bands with broader bandwidth. Thus by directing the radiated power in specific directions, the signal strength can be improved with reduced interference. All these had improved the gain and radiation efficiency of the antenna. The improved performance of the antenna will be beneficial in boosting the signal strength for high frequency applications. Thus the designed antenna can be used as a potential candidate for FR2 in 5G mmWave communications where propagation losses are higher.

4. Conclusions

The design and analysis of a slotted patch antenna from a simple patch antenna for high gain multiband operation in the Frequency range 2 (24.25 GHz to 52.60 GHz) in Rogers RT duroid substrate is discussed in this work. The designed slotted patch antenna operate in multiple frequency bands - 24.4 GHz, 30.2 GHz, 34.1 GHz, 45.7 GHz and 52.2 GHz with high gain of 13.83 dB, 7.30 dB, 8.65 dB, 11.49 dB and 13.49 dB at the respective frequencies. All these frequencies have broader bandwidth with good return loss characteristics. This antenna can be used for communication applications and can be used as a single element for designing array antennas or for MIMO antennas for 5G beamforming applications.

5. Acknowledgements

We express our gratitude to our Chancellor Sri. (Dr.) Mata Amritanandamayi Devi (Amma) for her inspiration and support towards working on interdisciplinary research that has direct societal benefit.

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