Design of Rectangular Slotted Microstrip Patch Antenna for 5G Applications at 27GHz

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2022 International Conference on Intelligent Innovations in Engineering and Technology (ICIIET) | 978-1-6654-5653-1/22/$31.00 ©2022 IEEE | DOI: 10.1109/ICIIET55458.2022.9967679

***Abstract*—In this digital creation of the 5G communication system, high-speed data, and greater bandwidth are the common needs. Hence, a simple structure of inset feed rectangular microstrip patch antenna is presented initially for 5G applications with a resonance frequency of 27 GHz. Later, a rectangular slot is introduced in the proposed microstrip patch antenna. This inclusion of slot results from an additional enhancement in the bandwidth as much as 1.51 GHz and acceptable return loss of -15.28 dB, appreciable VSWR of 1.41, and significant directivity of 8dBi. All the simulations and analyses are done using CST studio software and also compared with similar works. Although fabrication has not been done at this stage, we believe that this simple slotted rectangular patch structure will be a potential candidate for a 5G antenna operating at 27GHz.**

***Index Terms*—Rectangular microstrip patch, 5G application, Bandwidth, Return loss, Slotted antenna, Inset feed**

I. Introduction

During COVID and post-COVID scenarios, high-speed internet, and greater connectivity is a highly demanding aspects of day-to-day life. Online education helps our education system to maintain the standard in terms of class conduction or conducting labs during a lockdown situation. Whether it has been online education or work from home, large bandwidth and high-speed data rate [1] are needed every time especially when high-resolution videos are streaming. Consequently, the speed requirement is higher than the present 4G wireless system in India. Hence, it is needed to shift towards 5G technology from existing 4G systems and it is important to upgrade the existing system for 5G applications. In developing countries like India, the allocated frequency spectrum of 5G (millimeter wave) is 24.5-29.5GHz [2].

Owing to its small length, modest value, less weight, and simplicity of fabricating [2] microstrip patch antennas play a very important function in many applications like satellite communication, radar, plane, cellular communication, and many extras. The microstrip patch antenna is sandwiched between two conducting layers separated through a skinny dielectric substrate. The lower conductor is denoted as the ground plane and the top conductor is denoted as the patch. The patch is commonly manufactured from copper or gold. This metal patch has precise shapes consisting of round, rectangular, rectangle, circular, hexagonal, elliptical, triangular, etc. [3]. Rectangular or rectangular and circular are commonly shaped patch antennas. Rectangular microstrip patch antennas are made from a rectangular patch over a substrate floor with its width w_g, length$L$, substrate thickness h, and relative permittivity ε_r of the dielectric substrate. There is a diverse manner for feeding the microstrip patch antenna such as microstrip line, coaxial feed, etc. A fringing field occurs on the discontinuity side of the patch antenna and it brings radiation.

Many authors proposed and designed microstrip antenna for 5G applications. Goyal et al. (2018) [4] have presented a rectangular patch antenna with a return loss of -18.25 dB and bandwidth of 1.1GHz and gain of 6.83dBi. Imran et al. (2018) [5] have come up with a rectangular patch antenna for 5G cell verbal exchange for dual-band (38GHz, 54GHz). On the other hand, Ibrahim et al. (2018) [6] proposed a dual-band microstrip antenna at 28 GHz with a return loss of -16dB and bandwidth of 1.44GHz [6]. Kumar et al. (2019) [7] have presented a circular patch antenna at 28GHz with 0.792GHz bandwidth and a return loss of -43dB. Punith et al. (2020) [8] proposed a microstrip patch antenna operating at 23.9GHz, 35.5GHz, and 70.9GHz suitable for 5G and space applications. From the above survey, it has been found that a patch antenna with a resonance frequency of 27GHz has not been utilized previously for 5G applications. Hence, the authors took the initiative to propose a rectangular patch antenna with a resonance frequency of 27 GHz.

So, a new wireless standard 5G application with a patch antenna is still a fascinating task for researchers in the field of electronics. In this paper, a rectangular fashioned patch antenna is proposed with the resonance frequency of 27GHz and all the simulation is done by the usage of CST Studio [9]. However, the 5G antenna design requires more bandwidth to support high-speed connectivity. But, a microstrip antenna provides narrow bandwidth normally. To mitigate the shortcomings, different slots and slits, notches are created in the patch. So, a rectangular slot [10] is introduced within the current patch antenna to provide low return loss, good gain, and high bandwidth. This paper is assembled as follows: Order II describes different design parameters of the proposed rectangular microstrip patch antenna at 27GHZ. Next, simulation results (using CST studio) are given and also compared with existing techniques in Section III followed by a conclusion and references.

II. Proposed Design Of Patch Antenna

The condition for patch designing is $h_t \ll \lambda_0$. The range is normally $0.03\lambda_0 \leq h \leq 0.05\lambda_0$ 0.003 for the top h of the dielectric substrate [2]. The variety of relative permittivity of the substrate (ε_r) is within $2.2 \leq \varepsilon_r \leq 12$. For designing a microstrip patch antenna, the selection of frequency and substrate fabric performs a very crucial role. In this work, the resonance frequency or center frequency is selected as 27GHz which is inside 5G bands with a lower bound frequency of 20 GHz and upper bound frequency of 40 GHz.

The substrate is chosen as Rogers RT 5880 with dielectric regular 2.2 and loss tangent 0.0010. The dielectric of the substrate controls the bandwidth and gain values of the antenna. Loss Tangent can be expressed as the quantity of the electromagnetic wave passing through a dielectric that is absorbed or misplaced within the dielectric. So, substances with low loss tangents were taken into consideration. Also, high efficiency and greater bandwidth result in a compromise in the relative permittivity of the substrate. Moreover, the low relative permittivity of the dielectric has elevated fringing effects. Hence, the authors have chosen lower dielectric material in this work as it offers extra bandwidth and higher performance with compromise in the fringing field [11]. The top of the substrate h also governs the bandwidth as an increment in substrate height, floor wave, and spurious feed radiation will increase (i.e., undesired radiation and can couple to different components) which restricts the bandwidth [12].

The height for the substrate materials (h) for the rectangular microstrip patch antenna is 0.78mm. There are several methods for feeding the patch antennas. In this paper, an inset feed line [13] is used for feeding the rectangular microstrip patch antenna which is very efficient in terms of impedance matching. We have considered $Z_o = 50$Ohm.

The length and width of the antenna may be evaluated out through the usage of the subsequent equations [2]:

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

where μ_0 is permeability in free space, ε_0 is permittivity in free space,f_r is the resonant frequency, ε_r is the relative permittivity of the substrate

$$L = L_{eff} - L \tag{2}$$

where L_{eff} is the effective length of the patch can be expressed as

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \tag{3}$$

where ε_{eff} is the effective relative permittivity given as follows:

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}(1+\frac{12h}{W})^{-\frac{1}{2}} \tag{4}$$

and L is the length extension given as follows:

$$L = 0.412h\frac{(\varepsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{eff}-0.258)(\frac{W}{h}+0.8)} \tag{5}$$

The corresponding length L_g and width W_g of the substrate and height of the substrate h roughly indicate the dimension (length×width×height) of the patch antenna. These values are found in the given equations.

$$L_g = L + 6h \tag{6}$$

$$W_g = W + 6h \tag{7}$$

By using the above equations, the dimensions of a conventional inset feed rectangular patch microstrip antenna had been designed at the resonant frequency of 27GHz, $h = 0.78mm$, $\varepsilon_r = 2.2$. The thickness of the metal patch is taken as 0.0175mm. Next, the structure is further modified by inserting a rectangular slot into the upper metallic patch to improve the performance (i.e., return loss, VSWR, gain, etc.) of the patch antenna. The different parameters for both antennas are given in Table 1. Moreover, the schematic of the rectangular slotted microstrip patch antenna is shown in Fig.1. for more clarity.

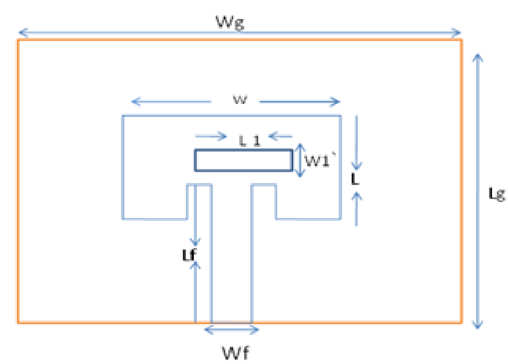

Fig. 1. Outline of slotted rectangular patch antenna

TABLE I
THE PARAMETERS FOR THE PROPOSED MICROSTRIP PATCH ANTENNA

Conventional Rectangular patch antenna dimensions with inset feed line (in mm)	
Patch Width (W)	4.38
Patch Length (L)	3.20
Width of ground (W_g)	8
Length of ground (L_g)	8
Width of feed (W_f)	2.42
Length of feed (L_f)	4.40
Height of Substrate (h)	.78
Rectangular slotted microstrip patch antenna dimensions (in mm)	
Slot Width (W_1)	1.5
Slot Length (L_1)	2

III. Result And Discussion

All the patch antennas were designed and implemented with the usage of the CST studio suite [9]. Initially, the authors come up with a conventional rectangular microstrip patch antenna (as per the parameters shown in Table 1), and VSWR, return loss, and gain were observed. Next, the conventional antenna is modified by inserting a rectangular slot in the upper metallic patch which provides an extra enhancement in the bandwidth and satisfactory value for return loss, VSWR. Now, different results corresponding to the conventional and proposed slotted microstrip patch antenna are discussed below.

A. Structure of the antenna

Perspective observations of the conventional and slotted rectangular-shaped microstrip patch antenna (with inset feed line) are shown in the following figures.

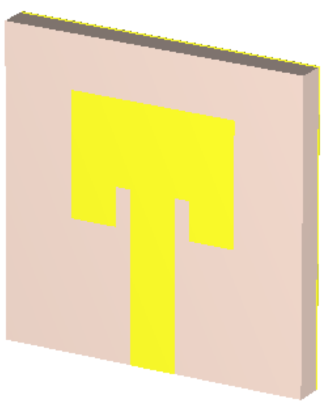

Fig. 2. Perspective observation of conventional rectangular patch antenna (using CST Studio)

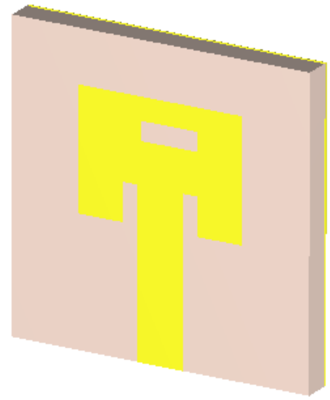

Fig. 3. Perspective observation of proposed rectangular slotted patch antenna (using CST Studio)

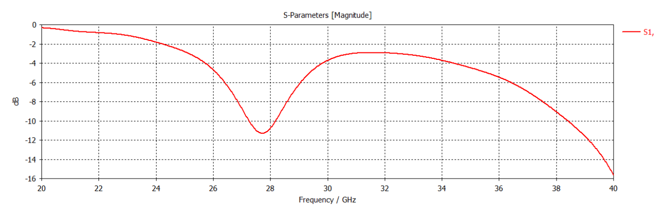

Fig. 4. Return loss for conventional rectangular patch antenna

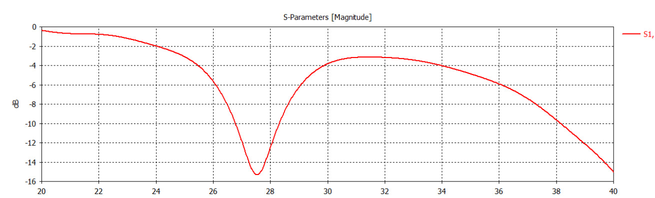

Fig. 5. Return loss for rectangular slotted patch antenna

B. Return Loss

Return Loss is expressed by S_{11} which indicates how much quantity of power reflects the transmitter from an antenna. Return loss should be at least -10 dB to be said as good. Bandwidth is generally laid out in phrases of a return loss. As shown in Fig. 4 return loss is -11.28 dB and bandwidth is 0.93 GHz for inset feed conventional rectangular patch antenna. With the insertion of the rectangular slot in the patch antenna, there is an additional enhancement in performance compared to the conventional rectangular microstrip patch antenna. The difference between higher and lower operating frequency is as much as 1.51 GHz i.e. bandwidth 1.51GHz which satisfies the characteristic of a 5G system and also provides a better return loss of -15.28dB. The corresponding return loss graph for the proposed slotted patch antenna is shown in Fig. 5.

C. Voltage Standing Wave Ratio

The best values of VSWR have to lie between 1 and 2 [14] for a patch antenna. Larger values of VSWR indicate an extra mismatch in impedance. The proposed conventional antenna gives a VSWR value of 1.92 at 27 GHz. The same antenna with a slot gives a VSWR value of 1.41 which is good for the radiation properties of the antenna. So, the proposed slotted antenna has better VSWR than the conventional one. Fig. 6 and Fig. 7 show the VSWR plot for conventional and slotted rectangular patch antenna respectively.

D. Radiation Pattern

Fig. 8 denotes the 3D far-field pattern of a conventional rectangular patch antenna with a directivity 7.92dBi and a gain of 6.76dB. On the other hand, Fig. 9 shows the 3D far-field pattern of a slotted rectangular patch antenna with a directivity of 8dBi and gain of 6.85 dB which is good for 5G applications.

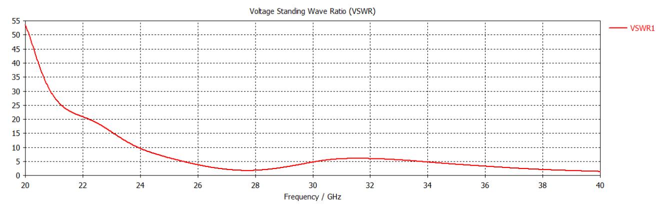

Fig. 6. VSWR of conventional rectangular patch antenna

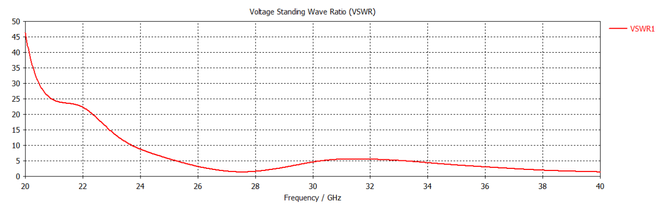

Fig. 7. VSWR of slotted rectangular patch antenna

Therefore, it can be concluded that a slotted patch antenna provides an increment in directivity and gain.

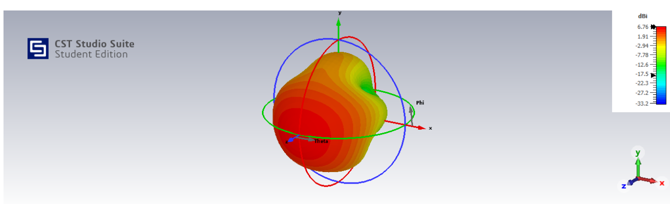

Fig. 8. Radiation Pattern for conventional rectangular patch antenna

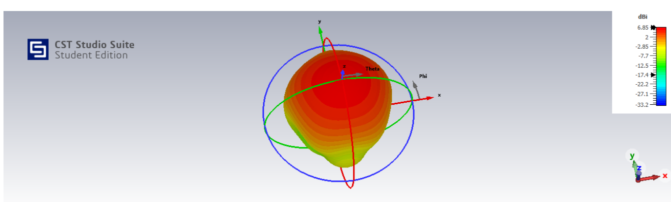

Fig. 9. Radiation Pattern for slotted rectangular patch antenna

E. Surface Current Distribution

It indicates the motion of electrical phenomenon which generates the contemporary densities at the patched floor which gives precise dissipation to the antenna can be shown in the following figures.

The authors have compared all the outcomes of our proposed work with earlier works [4], [6], [7] and found that our work outperforms earlier works in terms of bandwidth and good gain. However, these 5G antennae have a resonance frequency has 28GHz whereas the proposed slotted patch antenna operates at 27GHz. The comparisons are shown in Table II.

So far, the authors are not able to fabricate the proposed model in due time. But it is believed that all results will be

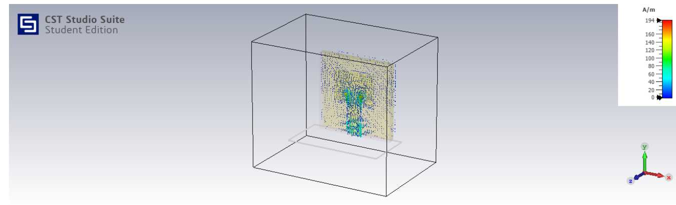

Fig. 10. Surface current of conventional rectangular patch antenna

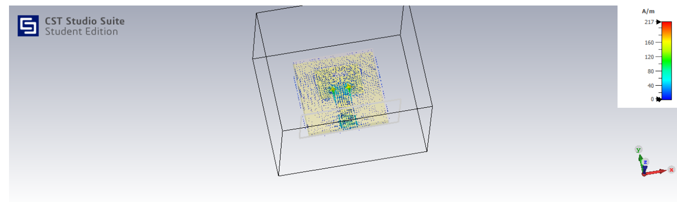

Fig. 11. Surface current with slotted rectangular patch antenna

TABLE II
COMPARISON WITH SIMILAR WORK FOR 5G

Works	Resonant Frequency (GHz)	Return Loss (dB)	Bandwidth (GHz)	Gain (dBi)
[4]	28	-18.25	1.1	6.83
[6]	28	-16	1.44	2.28
[7]	28	-43	0.792	7.69 (Directivity)
Proposed slotted patch	27	-15.28	1.51	6.85 (Directivity=8 dBi)

validated with simulation results. One of the main advantages of the propsed slotted rectangular microstrip patch antenna is its simplicity in structure. Without using the complicated slot and cut-in patch design, by using the proposed simple and effective rectangular slotted patch antenna, authors can able to achieve satisfactory return loss, VSWR, and gain for the 5G application.

IV. CONCLUSION

In this work, a conventional inset feed rectangular microstrip patch antenna and a rectangular slotted microstrip patch antenna (at resonant frequency 27GHz) are designed and efficiently implemented using CST studio. From the simulation results, it has been visible that a slotted rectangular patch microstrip antenna gives improved bandwidth, high gain, and high directivity and such benefits are vital for 5G applications. Optimal overall performance can be done utilizing controlling numerous parameters inside the antenna via slot top, width, etc. Higher gain can be carried out utilizing constructing an antenna with an array of elements. Multispectral patch antenna for 5G domains is another direction for future research.

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