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Design and analysis of microstrip patch antenna for 5G wireless communication systems

Md. Sohel Rana, Md. Mostafizur Rahman Smieee
Department of Electronics and Communication Engineering, Khulna University of Engineering and Technology, Khulna, Bangladesh

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ABSTRACT

Due to lower latency, greater transmission speed, wider bandwidth, and the possibility to connect with greater multiple devices, fifth-generation (5G) networks are far better than 4G. In this study, a microstrip patch antenna operating at 28 GHz is investigated and modeled for future 5G communication technologies. The substrate used in this work for the antenna is Rogers RT/Duroid5880. Dielectric of the substrate is 2.2 and thickness is 0.3451 mm. CST software is used to simulate the antenna as it is convenient to use. From the simulation, the return loss, gain, radiation efficiency, side-lobe level was found to be -38.348 dB, 8.198dB, 77%, and -18.3 dB respectively. The result found from this simulation is better than the works took place in the past. As a result, it can be utilized as a capable candidate for 5G wireless technology. The results of this proposed antenna are superior to those of existing antennas published in recent scientific journals. As a result, it's likely that this antenna will meet the needs of 5G wireless communication systems.

Corresponding Author:

Md. Sohel Rana
Department of Electronics and Communication Engineering
Khulna University of Engineering and Technology
Khulna-9203, Bangladesh
Email: sohel.rana@uits.edu.bd

1. INTRODUCTION

Microstrip patch antennas play an increasingly important part in current wireless communication systems. There are many different types of antennas, some of which are folding dipole antennas, slot antennas, patch antennas, and parabolic reflectors. Each variety of antennas has its own set of characteristics as well as a particular application. We may say that antennas are the backbone of practically everything in wireless communication, without which the world could not have reached this age of technology and there are different types of applications in the current age of technology [1].

Radio frequency (RF) and wireless communication technologies are now widely utilized in everyday human activities and various industrial applications. Many wireless communication technologies have arisen in recent years, including wireless local area network, wireless interoperability for microwave access, wireless broadband, and so on. The microstrip patch antenna is a good fit for RF communication system needs, and it has poor gain, a disordered radiation pattern, and limited bandwidth [2].

Researchers and scientists have been engaged in this topic because of the extensive range of wireless applications. Many researchers have published the concept of a microstrip patch antenna, which may be produced on printed circuit boards and is a new technology in electronics [3]. These are extremely important in today's wireless communication systems. The term "antenna" is derived from the Latin word "antenna." The IEEE defines an antenna as “a component of a transmitting or receiving system designed to radiate or receive electromagnetic waves”.

Microstrip antennae are extremely simple to build using a traditional microstrip fabrication technique. A substrate with a higher dielectric constant must be used to design a compact microstrip patch antenna, resulting in lower efficiency. In the era of modern technology, applications of fifth-generation (5G) are growing fast. It can provide many services, such as medical treatment and remote control of industrial equipment. It also improves the safety of society ensuring security and boosts the development of the economic growth of a country. As we step into the 4^{th} industrial revolution, the demand of people across the world have increased to a large extend which can be served only by 5G applications.

The 5G wireless communication system has become the most significant part of our life. In our day-to-day life, all most all the devices are dependent on it. 4G systems cannot provide the demand of the people across the world due to its low speed, unstable connections, and loss of streaming capabilities. Whereas 5G is able to provide high speed, stable connections, and higher bandwidth, and most importantly, the transmission delay is much less as compared to 4G. 5G networks will be used by industries and consumers in many purposes, especially in wireless devices.

A microstrip patch antenna can be a great deal for the 5G applications [4]. It can provide higher bandwidth, higher efficenciy, low power consumption and high gain [5], [6]. To ensure maximum energy, high gain is a must in antenna technology. In this work, Rogers is used as a substrate as it has the capability to work at a higher frequency [7]. This work designs and analyzes a microstrip patch antenna for 5G communication, which is designed to resonate at 28 GHz.

2. LITERATURE REVIEW

Patch antennas have a very important function to fulfill in the world of wireless communication networks that we live in today. The building of a microstrip patch antenna is fairly straightforward and it employs a microstrip fabrication method that is more commonly used. The patch can be configured in any way imaginable; however, the rectangular and circular configurations are the ones that are used the most frequently. These patch antennas are put to use in the simplest way possible for the broadest range of applications that are also the most demanding [1]. This section discusses the technical work of different papers of microstrip patch antennas.

A broadband elliptical-shaped slot antenna that can be used for future wireless applications of the 5G is proposed in this article [8]. The suggested antenna for 5G communication achieves a broadband impedance bandwidth of greater than 67 percent (from 20 GHz to beyond 40 GHz) at S11 values of less than -10 dB. The bandwidth that was accomplished is sufficient to span both of the forthcoming 5G bands (28/38 GHz). The suggested antenna possesses almost omnidirectional patterns, relatively flat gain, and good radiation efficiency across the frequency band, with the exception of the band that would be rejected.

In this study, [9] different designs for rectangular microstrip antennas are presented. One of the typical frequencies for 5G communications is 28 GHz and these antennas all operate at that frequency. In order to achieve more accurate impedance matching, an array arrangement makes use of a corporate feeding network. It enhances performance factors such as returns loss characteristics, impedance bandwidth, gain, and radiation pattern. Other performance metrics that benefit from this are gain and directivity. In conclusion, this eight-element microstrip patch array that has been proposed along with its modified corporate feeding is an excellent option for potential future 5G applications.

This article presents [10] a dual-band printed slot antenna as a potential solution for 5G mobile network infrastructure in the future. The suggested antenna offers almost omnidirectional patterns, relatively flat gain, and good radiation efficiency across the entire frequency band, with the exception of the band that would be rejected. The suggested dual-band antenna has been shown to have a dual-band response for the 5G system at both 28 and 38 GHz, as shown by the results of simulations. An L-shaped slot is etched out in the feed line to form a notched band in the frequency range of 30–35 GHz. This is done to limit the amount of interference that occurs between the 5G system and other applications. The dual-band antennas that are being considered have a gain of up to 7 dBi, although there is a significant decrease in the notched-frequency band near 31 GHz.

The investigations conducted [11] in this study focused on utilizing a wide variety of microstrip antenna configurations. Antenna performance can be evaluated based on several critical characteristics, including return loss, voltage standing wave ratio (VSWR), bandwidth, resonant frequency, and gain. A return loss of less than -10 dB is considered to be an outstanding value. The value range of VSWR that is taken into consideration is 1-2. CST microwave studio is a cutting-edge software application that enables users to create and evaluate a wide variety of antennas, filters, and other types of devices.

For use in 5G communication applications, the study describes [12] a high-gain linear 1×4 antenna array that is constructed utilizing a circular slotted patch. The suggested antenna has been developed for a frequency of 28 GHz and is capable of supporting TM11 as a fundamental mode when it is tuned to resonance. The concept of the proposed antenna has been validated through the use of a vector network analysers (VNA) and an anechoic chamber to characterize the prototype of the antenna. The suggested array antenna has a central frequency of 28 GHz, a return loss of 16 dB, and an impedance bandwidth of 10 dB that spans 10 percent of the millimeter-wave band between 24.6 and 27.24 GHz.

Research by Al-Gburi *et al*. [13], 3.5 GHz hexagonal microstrip patch antennas are designed and simulated. Four types of antennas, from single elements to 1×8 arrays, were simulated using CST software. The proposed 1×8 array antenna has a microstrip feed line. Its directional radiation helps the base station provide high-quality, high-capacity network connectivity. This antenna is for long-distance point-to-point connections. The final antenna had a 6.938 dB gain at 3.5 GHz and a -10 dB return loss.

According to the research paper [14], the antenna operates at 27.97 GHz and has a directivity of 7.6 dB, a bandwidth of 1.06 GHz, 7.5 dB, and a reflection coefficient of -20.95 dB. Additionally, its efficiency is 99.98%. An investigation into the design of patch antennas for use in 5G wireless communication systems is provided here.

In this study [15], a microstrip patch antenna serves as a communication device that is examined for one-band and dual-band communication at higher frequencies. This research was carried out in the United States (mm-waves). This is a dual-band version of the U-shaped slotted microstrip patch antenna with working bands of 28 GHz and 38 GHz. The Rogers RT 5880 material, which has a dielectric constant of 2.2, was utilized across the entirety of the antenna substrate during the design process. At a frequency of 28 GHz, the antenna had a return loss of -32 dB, while at a frequency of 38 GHz, it was -40 dB. Simulations showed that the proposed dual band would have a gain of 7.92 dB at 38 GHz and 6.7 dB at 28 GHz.

For the purpose of mmWave wireless communication, a square-slotted microstrip patch antenna with a resonance frequency of 37 GHz is presented in this study [16]. The radiating patch is loaded atop the antenna, which comprises of an H-slot and an inverted T-slot. Using the electromagnetic simulation software CST microwave studio, the suggested antenna has been built and investigated on the Rogers RT5880 substrate, which has a relative permittivity of 2.2 and a loss tangent of 0.0009, respectively. A minimal return loss of -43.05 dB, a gain of 8.18 dB, and an impedance bandwidth of 16.22 percent were found to exist at the resonant frequency of 37 GHz in this paper's findings.

In this paper [17], a 1×2 array microstrip rectangular patch antenna consisting of two elements is designed. The patch on the antenna is 19.5 millimeters by 26.5 millimeters, and it has a frequency of 3.5 GHz and array size of 1×2. The design of the antenna is created in a simulation that operates at a frequency of 3.5 GHz; the substrate material is made of flame retardant (FR) 4, which has a constant of 4.3, and the patch materials are built of copper. The frequency at which the simulation operates is 3.5 GHz.

This article presents [18] the design and analysis of a microstrip patch antenna for use in 5G applications that operate in the frequency range of 24.5 to 50 GHz for 5G waves. using high frequency structure simulator (HFSS) software, a simulation and analysis of this design have been performed. The proposed antenna was successful in resonating at three different frequencies: 31 GHz, 34.2 GHz, and 38.4 GHz by employing slotting techniques with favorable return loss, favorable gain, and VSWR less than 2. This concept is beneficial for establishing wireless communications and gaining access to the internet at a fast speed.

3. ANTENNA DESIGN

A microstrip patch antenna is most typically employed to radiate the electromagnetic wave into space in wireless communication. Ground, substrate, patch, and feed are the four main components of a microstrip patch antenna. It comes in various shapes, including square, ellipse, circular, rectangular, and ring, and consists of a dielectric constant on one side and a ground plane on the other. Microstrip patch antennas are utilized in various application including automotive, logistics tracking, global positioning system (GPS), and microwave communication. Figure 1 shows a microstrip antenna with W as the width, L as the length, and ε_{reff} as the effective dielectric constant of the rectangular patch [3].

This section discusses the design and development of a patch antenna for wireless communication because it is well known that it can be mounted on a printed circuit board (PCB) for various communication devices. As a result, researchers devised different patch antenna designs for wireless applications with this in mind. IE3D, HFSS, CST, MATLAB, and other simulation software are available for designing, simulating, and analyzing microstrip antennas. Figure 2 shows the dimensions of the antenna, including the length, and width of the ground, patch, substrate, and feed line. To design, develop, and simulate the micro strip patch antenna, CST microwave studio was used. This paper used RT/Duroid5880 as the substrate material in this proposed prototype patch antenna design, which dielectric of the substrate is 2.2 and thickness is 0.3451 mm. Figure 3 shows the simulation of the microstrip patch antenna.

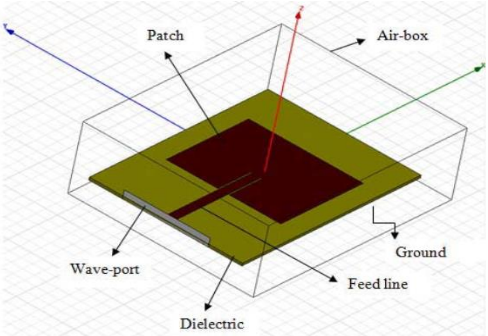

Figure 1. Microstrip patch antenna

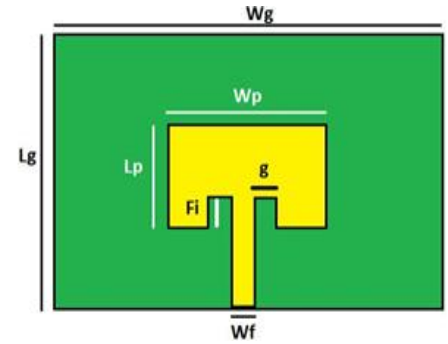

Figure 2. IEEE 33-bus radial system

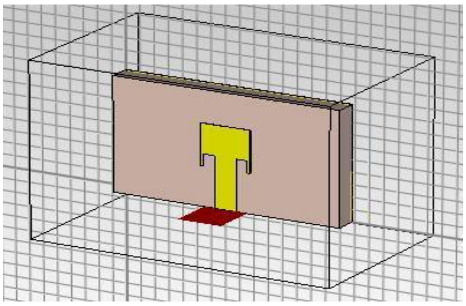

Figure 3. Simulation of the microstrip patch antenna in CST

The following equations are used in this work to calculate the parameters [19], [20].

a. Microstrip patch antenna width

$$Wp = \frac{c_0}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \quad (1)$$

b. The effective dielectric constant

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1 + 12 * \frac{h}{w}\right)^{-.5} \quad (2)$$

c. Extended length

$$L_{ext} = \frac{c_o}{2f_r\sqrt{\varepsilon_{reff}}} \quad (3)$$

The following equation is used to get rid of the fringing effect, and thus, the actual length of the patch is obtained.

$$\Delta L = 0.412 \frac{\left(\frac{w}{h}+.264\right)\left(\varepsilon_{reff}+.3\right)}{\left(\varepsilon_{reff}-.258\right)\left(\frac{w}{h}+.813\right)} \quad (4)$$

$$L = L_{ext} - 2\Delta L \quad (5)$$

A 50-ohm inset feed transmission feed line was used to connect to the patch of the antenna.

d. Feed line width

$$W_f = \frac{7.48h}{e^{\left(z_0\frac{\sqrt{\varepsilon_r+1.41}}{87}\right)}} - 1.25t \quad (6)$$

The measurements of the antenna are included in Table 1. Both the width and the length of the ground are denoted by the notation Wg and Lg, respectively. Besides, antenna patch width (W_p), length (L_p) along with height of substrate (H_s) and thickness (t) are given. The values of the various components are represented by some other parameters.

Table 1. Antenna parameters after optimization

Parameter	Dimension (mm)
Ground plane width, Wg	15.8
Ground plane length, Lg	9.83
Patch width, Wp	4.25
Patch length, Lp	3.5
Height of substrate, Hs	1.575
Feedline width, Wf	1.5
Feedline inspection, Fi	0.25
Ground thickness, t	0.035
Gap (patch – feedline)	0.783

4. RESULTS AND DISCUSSION

4.1. Return loss

The parameter was determined to be accurate based on the simulation's final results. The base value is -10 dB, which is ideal for mobile or wireless technology. The antenna is tuned to the required frequency to function properly. As can be seen in Figure 4, it runs at a frequency of 28 GHz. At this frequency, the return loss was measured to be -38.348 dB. S_{11} parameter describes the return loss of the designed antenna. From the Figure 4, value of the return loss at -10 dB is -38.348 dB which is very high ensuring perfect candidate for 5G applications.

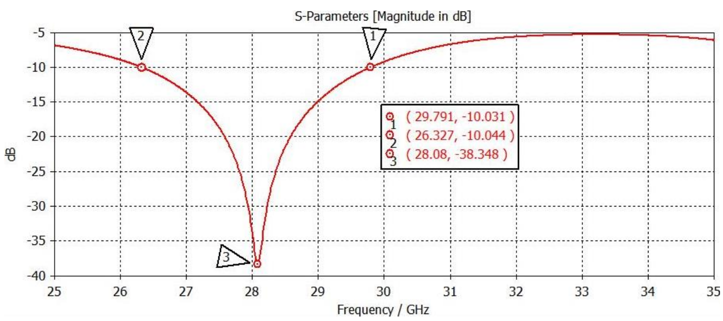

Figure 4. Return loss vs frequency of the antenna

4.2. Bandwidth

From the Figure 4 bandwidth of the antenna is 3.464 GHz between 26.327 GHz and 29.791 GHz. For the 5G applications, higher bandwidth plays an important role. In this work, bandwidth achieved is perfect for these applications.

4.3. Voltage standing wave ratio

VSWR is an important parameter to identify the antenna's performance as it describes how well the impedance of the transmission line is matched. The bandwidth for the VSWR should be close to 1 to get better performance. Figure 5 shows that the VSWR value is 1.024485 and it is very close to the ideal value which is 1.

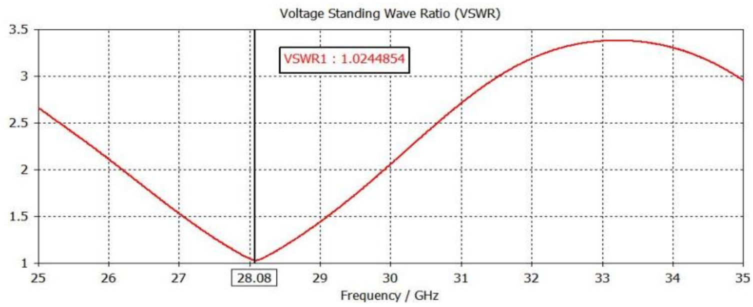

Figure 5. VSWR vs frequency of the microstirp patch antenna

4.4. Surface current, H field, and E field

The antenna's surface current, H field, and E field were observed and demonstrated in Figures 6-8. The surface current is a real electric current that is caused by an applied electromagnetic field. The E-field is a vector quantity, meaning it has a magnitude and a direction at each point in space. The performance of a microstrip antenna is significantly influenced by fringe fields. The electric field at the patch's center is zero with microstrip antennas. The fringing field between the patch's periphery and the ground plane is responsible for the radiation. H Field represents the magnetic strength of the antenna.

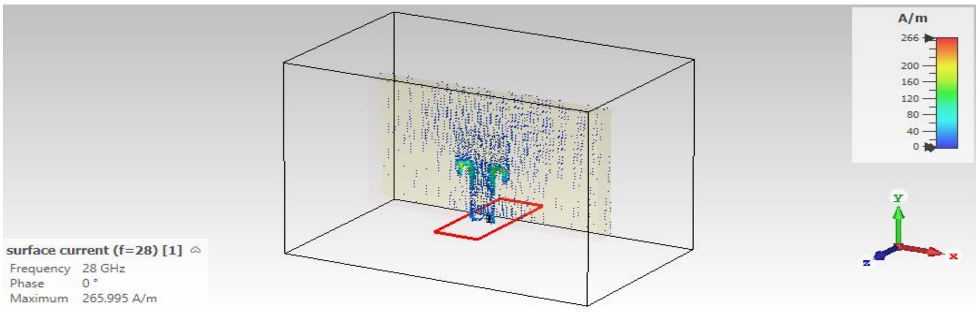

Figure 6. Surface current distribution of the antenna

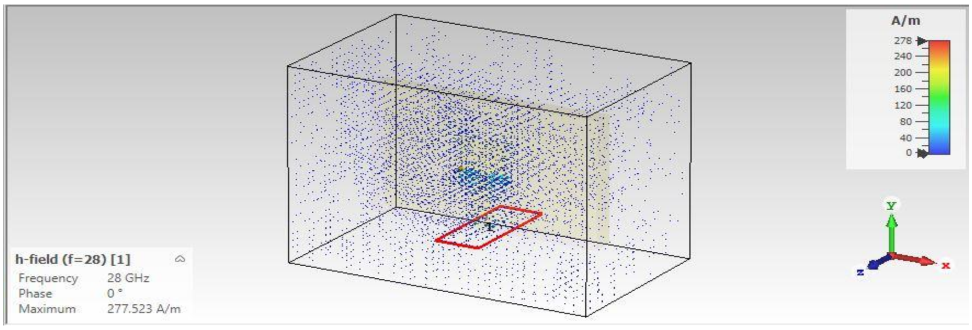

Figure 7. H field of the antenna

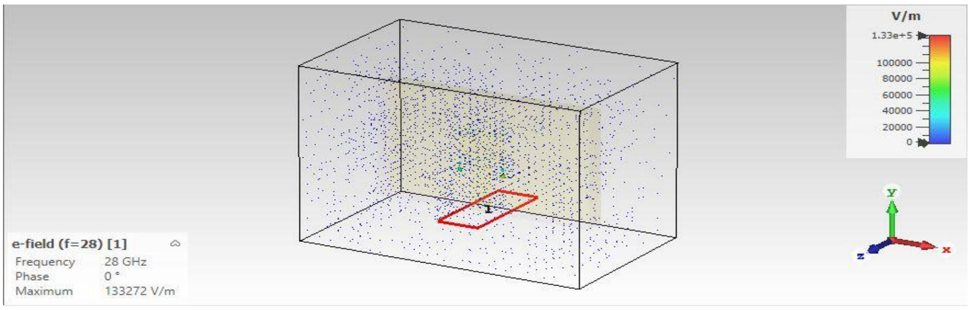

Figure 8. E field of the antenna

4.5. Gain and performance

The radiation pattern is an important feature since it demonstrates the overall performance of an antenna. Figure 9 shows the 3D radiation pattern of the microstrip patch antenna. From the figure, the gain is 8.2 dBi and the radiation efficiency is 77% which is very effective for 5G technology. In addition to that, from Figure 10, the main-lobe direction, angular width (3 dB), and side-lobe level are 11.0 degree, 72.5 degree, and -13.8 respectively. Table 2 summarizes the simulation results for the antenna designed and the previous scientific works. While propagating into the antenna, it results in impedance mismatch which is responsible for power consumption. Optimal design results in minimal power consumption reduced heating, and consistent data transfer. If the impedance is matched, it results in desired low VSWR which enables maximum power from the source to the load. From Table 2, compared with the previous works [21], [22], it is crystal clear that the studied antenna shows lower return loss. Moreover, it gives a lower VSWR than that of previous works [21], [23] took place. All the antenna parameters have been optimized in a way so that the studied antenna can achieve better performance in terms of gain and bandwidth. Table 2 shows that the bandwidth is greater than that of the antennas mentioned in [21], [22]. In comparison with the gain, the rectangular microstrip patch antenna in this paper performs better than the designs reported in [21], [22]. In general, the designed microstrip patch antenna performs exceedingly well when compared to previous works reported.

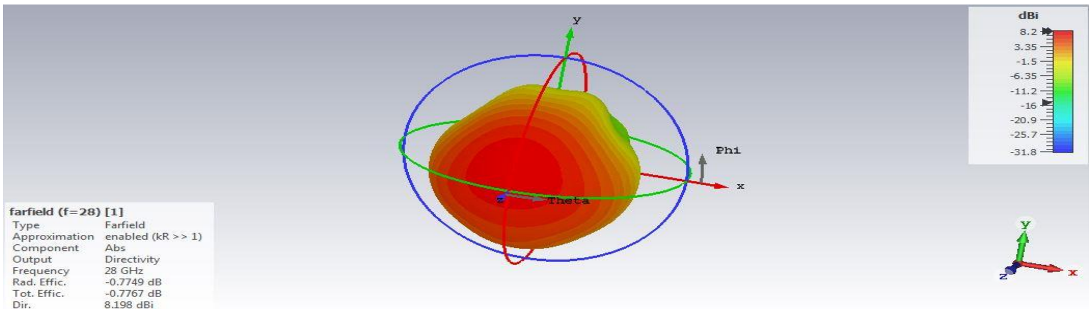

Figure 9. Antenna 3D radiation pattern

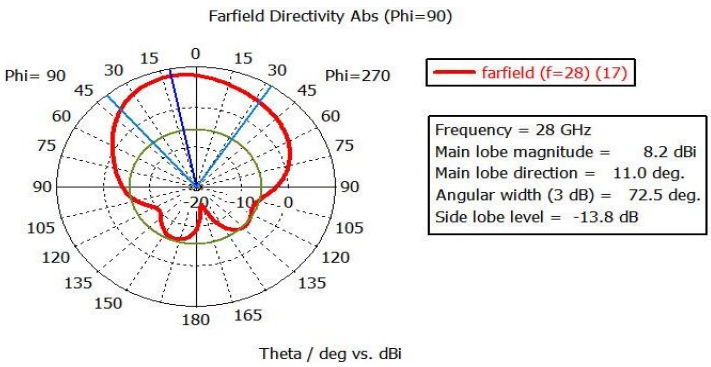

Figure 10. The microstirp patch antenna's 2D radiation pattern

Table 2. The findings of this research, as well as prior research on microstrip patch antennas, are presented

Ref.	S_{11} (dB)	Gain	VSWR	BW
[2]	-13.48	6.63	1.538	0.847 GHz
[3]	-18.27	4.46	2.13	0.2 GHz
[17]	-12.54	5.5	1.6	3.5 GHz
[24]	-19.61	6.58	1.82	10 GHz
[25]	-	9.21	-	27.3 GHz
[26]	-35	2.73	Less than 2	915 MHz
[27]	-20.03	5.23	1.22	2.11 GHz
[28]	-48.877	6.51	1.0072	3.088 GHz
[29]	-32.159	8.07	1.1429	3.848 GHz
[30]	-18.117	7.486	-	21.06 GHz
[31]	-	7.46	-	-
[32]	-33.4	10	-	3.5 GHz
[33]	-17.4	6.72	1.27	28 GHz
[34]	-42	9.82	-	1.29 GHz
[35]	-16	2.28	-	1.44 GHz
[36]	-43	7.69	-	0.769 GHz
[37]	-40.28	5.8	1.02	200 MHz
[38]	-22.10	3.53	1.16	27.7 GHz
[40]	-14.15	7.77	1.48	28 GHz
This work	-38.348	8.2	1.0244	3.464 GHz

5. CONCLUSION

For 5G technology, a compact-sized microstrip patch antenna is studied with a view to achieving high gain resonating at 28.08 GHz. According to the research, the gain, return loss, bandwidth, VSWR, and radiation efficiency found are 8.2, 38.348 dB, 3.464 GHz, 1.0244, and 77% respectively. These results show that the designed antenna is well built to be used in 5G technology. A further enhancement is possible by using different methods such as circular and ring-type array patches. Future research can use a variety of approaches and materials to produce good outcomes. The simulated results demonstrate that the proposed antenna could be a good contender for wireless communication systems. It can be built in the future to compare actual results to simulated results.

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BIOGRAPHIES OF AUTHORS

Md. Sohel Rana received a BSc Engineer degree in Electrical and Electronic Engineering from Prime University (PU), Bangladesh in 2015. He received a Master's degree in Telecommunication Engineering from the University of Information Technology and Sciences (UITS), Bangladesh, in 2018. Another master's degree was received from Bangladesh University of Professionals (BUP), Bangladesh in 2022. He is currently studying for a Ph.D. program at Khulna University of Engineering and Technology (KUET), Bangladesh in the Department of Electronics and Communication Engineering. His research interests include microstrip patch antennas, image processing, renewable energy, and power electronics. At present he is working as a lecturer in Northern University of Businesss and Technology, Khulna, Bangladesh. He can be contacted at email: sohel.rana@uits.edu.bd.

Dr. Md. Mostafizur Rahman Smieee received the Ph.D degree in Electrical, Electronic and Computer System Engineering (EECE) from Akita University, Japan in February, 2011. He received a master's degree in Electrical and Electronics Engineering (EEE) from Khulna University of Engineering and Technology (KUET), Bangladesh in 2005. Before this he received the B.Sc engineering degree in EEE from Bangladesh Institute of Technology (BIT), Rajshahi in 1992. He is a senior member of IEEE and life fellow of Engineering Institute of Bangladesh. He is also the member of Canadian council of professional engineers (CCPE). His research interests include antennas, electromagnetic hand motion capture system and wireless communications. At present he is working as a professor in the Department of Electronics and Communication Engineering (ECE) of KUET, Khulna, Bangladesh from 2012. He can be contacted at email: mostafiz963@yahoo.com.