Simulation and Optimization of Rectangular Microstrip Patch Antenna for Mobile 5G Communications

Hamzah M. Marhoon [1], Noorulden Basil [2], Hussein A. Abdualnabi [3], Ahmed R Ibrahim [4]

[1,2,4] Department of Computer Techniques Engineering, Al-Esraa University College, Iraq
[3] Department of Electrical Engineering, AL-Mustansiriyah University, Iraq

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ABSTRACT

Microstrip or patch antennas are becoming increasingly useful because they can be printed directly onto a circuit board. Microstrip antennas are becoming very widespread within the mobile phone market. Patch antennas are low fabrication cost, have lightweight, and are easily fabricated. The lightweight construction and the suitability for integration with integrated microwave circuits are two more of their numerous advantages. This work introduces a design of a rectangular Microstrip Patch Antenna (MPA) at a frequency of 28 GHz using the finite integration technique of the Computer Simulation Technology (CST). The simulated antenna is employed for the 5G mobile communication. The inset-fed technique has been used to feed the rectangular MPA because it is easy to fabricate and provides simplicity in modeling as well as impedance matching. In order to facilitate the fabrication and reach the best results, an attempt has been made to improve parameters through optimized patch dimensions by trial and error. A reasonable gain, bandwidth, radiation pattern, and return loss have been obtained after the antenna simulation process was completed.

Corresponding Author:

Hamzah M. Marhoon, Department of Computer Techniques Engineering, Al-Esraa University College, Iraq.
Email: hamzaalazawy33@yahoo.com

1. INTRODUCTION

Wireless communication plays a significant role in the day-to-day life. Besides communication, wireless technology has become an integral part of our daily activities. The transmission of data or information from one place to another witlessly is referred to as wireless communication. This provides an exchange of data without any conductor through Radio Frequency (RF) and microwave. The information is transmitted across the devices over some meters to hundreds of kilometers through well-defined channels. The term wireless refers to communication without wires. In order to transmit information such as voice or data using wireless communication, the essential part of completing the transmission process is the use of the antenna in the transmitter and receiver. The antenna is the device that couples RF energy from one medium (i.e., waveguide, transmission line, etc.) to the other medium (i.e., air). Wireless communication uses electromagnetic waves as a medium for carrying the information through the channel between transmitter and receiver [1]-[3].

In the last decade, the communication world has experienced a real revolution that was just a dream before. The technological advancement in the communication sector has led us to this stage through the secure wireless network, signal integrity in communications, and high-performance antennas. In the 1970s, the Bell lab devised a cellular system and developed the first standards to be commercially applicable and usable. The growth of demand increased more in commercial applications during the 1980s and 1990s, which helped to deploy modern wireless mobile services. During this journey, technological advancement increased significantly with the high consumer demand, while mobile communications are expected to reach 5G within 2020 to 2030, as illustrated in Fig. 1 [4]-[6].

With the help of the current wireless networks, it is possible to connect to the internet from mobile phones, tablets, and laptops. Nowadays, it is feasible to watch football and hockey on live streaming because of high-speed internet connectivity. Information and communication technology has advanced enough to have significant impacts on all aspects of life. Wireless data transfer is not only limited to communication purposes, but also it has a significant impact on medical, surveillance, and radio broadcasting. For higher data transmission, the wide bandwidth is mandatory, which can be realized by the utilization of upper-frequency bands. This fact directs both the industry and the research community to the millimeter-wave bands [7].
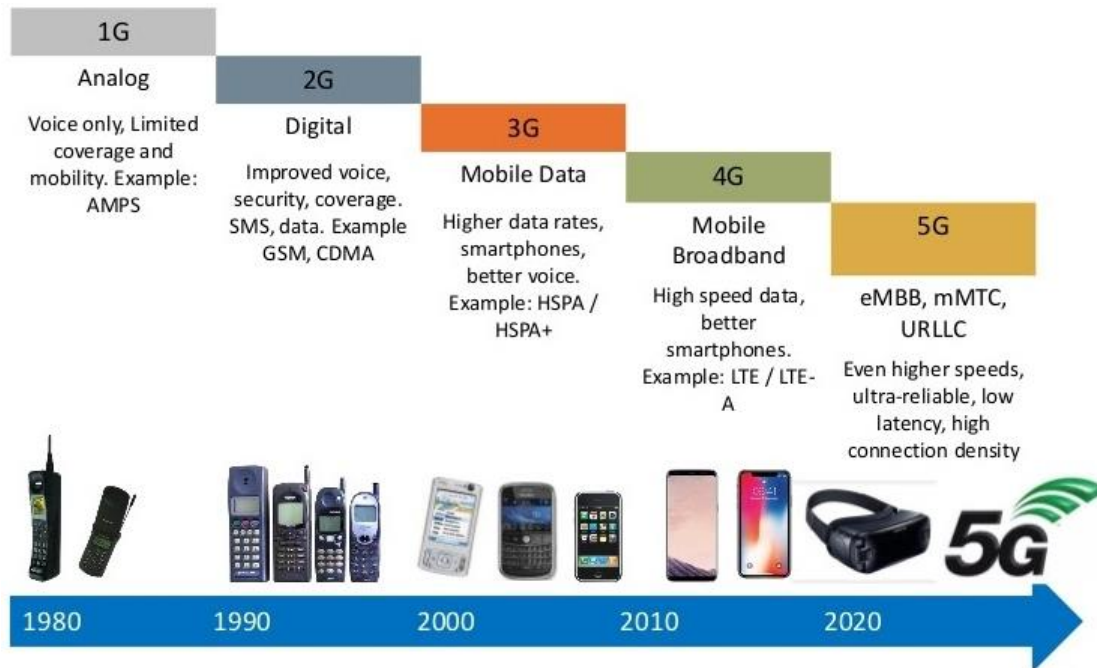

Fig. 1. Evolution of wireless communications

The microstrip antenna is a relatively modern invention. It was invented to allow convenient integration of an antenna and other driving circuitry of a communication system on a commonly printed circuit board or a semiconductor chip. Besides other resulting advantages, the integrated-circuit technology for the antenna fabrication allowed high dimensional accuracy, which was otherwise difficult to achieve in traditional fabrication methods. The geometry of a microstrip antenna consists of a dielectric substrate of a certain thickness named "d," having a complete metallization on one of its surfaces and a metal "patch" on the other side [8].

Fig. 2 illustrates the structure of the microstrip patch antenna, which consists of a very thin ($t \ll \lambda o$, where λo is the free-space wavelength) metallic strip (patch) placed a small fraction of a wavelength ($h \ll \lambda o$, usually $0.003\lambda o \leq h \leq 0.05\lambda o$) above a ground plane. The microstrip patch is designed, so its pattern maximum is normal to the patch (broadside radiator). This is accomplished by properly choosing the mode (field configuration) of excitation beneath the patch. End-fire radiation can also be accomplished by judicious mode selection. For a rectangular patch, the length L of the element is usually $\lambda o/3 < L < \lambda o/2$ [9][10].

In this paper, a compact size rectangular microstrip patch antenna will be designed, simulated, and optimized for 5G mobile communications. The proposed antenna is designed based on the finite integration technique provided by the CST antenna simulation software. The paper is organized as follows: Section 2 presents the antenna design specification. Section 3 presents the antenna design and simulation process by the CST antenna simulation software. Section 4 presents the obtained results from the CST software for the proposed antenna. Finally, Section 5 presents the paper's conclusion.

2. ANTENNA DESIGN SPECIFICATIONS

In order to design the proposed microstrip patch antenna, there are three essential parameters must be considered which are:

- Frequency of operation (f_r): The resonant frequency of the antenna must be selected according to the application used.

- The dielectric constant of the substrate (ε_r): The dielectric constants are usually in the range of $2 \leq \varepsilon_r \leq 12$.
- Height of dielectric substrate (h): For the MPA to be used in modern applications, it is essential that the antenna is not bulky.
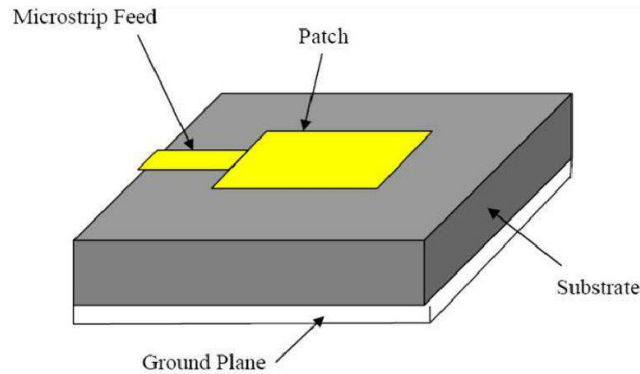

Fig. 2. Structure of microstrip patch antenna.

3. RECTANGULAR MICROSTRIP PATCH ANTENNA SIMULATION

This section of the paper discusses the design, simulation, and optimization process for the rectangular microstrip patch antenna. The antenna dimensions were calculated via the online "Microstrip Patch Antenna Calculator" after that, the simulation was carried out using the CST software. For the design of the rectangular microstrip patch antenna, the previously mentioned essential parameters are set, such as the frequency of operation, the dielectric constant of the substrate, the height of the dielectric substrate, as well as input impedance in Table 1.

Table 1. Essential parameters values

Parameter	Value
f_r	28 GHz
ε_r	2.2
h	0.1 mm
R_{in}	50 Ω

Optimization is the act of obtaining the best result under given circumstances. The word 'optimum' is taken to mean 'maximum' or 'minimum' depending on the circumstances. In this study, the main goals of optimization are to enhance the performance of the antenna. Therefore, the optimization procedures for the antenna are done by maximizing some parameters and minimizing some others to get the best results [11]. Table 2 presents the antenna dimensions before and after the optimization process.

Table 2. Calculated and optimized parameters for the simulated antenna

Parameter	Calculated Model	Optimized Value
Patch Width (W)	4.2351932948684	3.9
Patch Length (L)	3.5653586620833	2.955
Feed Inset from Edge of Patch (d)	0.85550766	0.9
Feed Line Width (W_f)	0.326	0.326
Feed Line Length (L_f)	2.38	2.38
Spacing between Feed Line and Patch (g)	0.12343	0.197

The final shape of the simulated rectangular microstrip patch antenna inside CST software is shown in Fig. 3, and the dimensions of the patch, feed line, and space between them are demonstrated in Fig. 4.

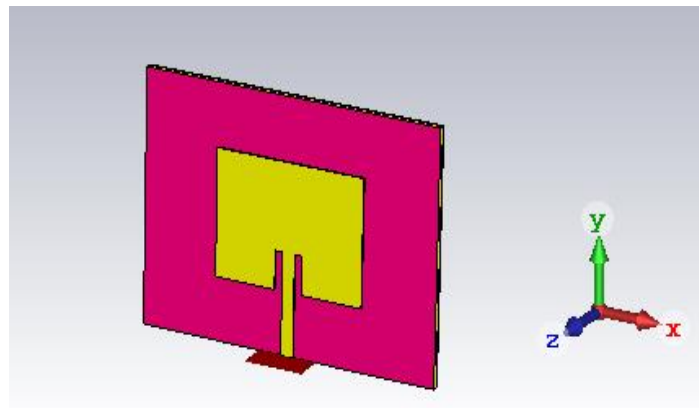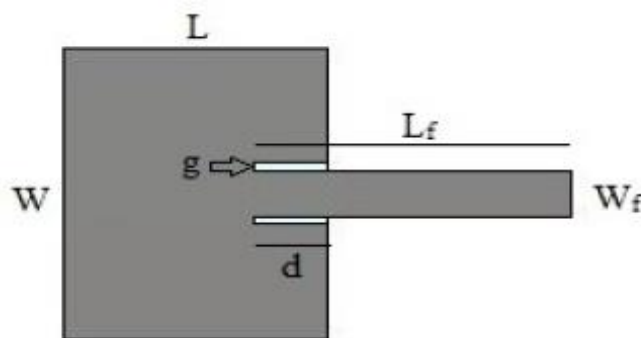**Fig. 3.** Optimized rectangular MPA in side CST-MWS

Fig. 4. Dimensions of patch and feed line.

4. SIMULATIONS RESULTS

In this section, the results of the simulated rectangular microstrip patch antenna that are obtained after completing the antenna simulation process will be presented and discussed.

4.1. Return Loss

Return loss is the reflection of signal power relative to the transmitted signal power. So, it needs to be as low as possible in order to have all the power transmitted. -10 dB return loss criteria mean only 10% of the incident power is reflected back to the source while the remaining 90% is passed to the load [12]. The return loss of the simulated rectangular microstrip patch antenna from CST software at 28GHz is about -30.5 dB, as shown in Fig. 5.
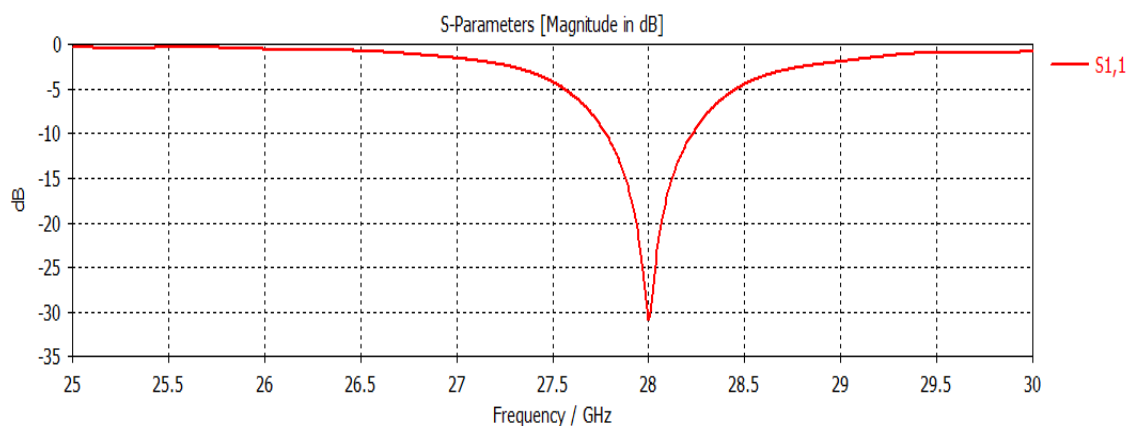

Fig. 5. Return loss of the antenna before the optimization.

4.2. Bandwidth

The bandwidth can be calculated from the return loss plot. The bandwidth of the antenna can be said to be the range of frequencies over which the return loss is greater than -9.5 dB [13]. The bandwidth of the rectangular microstrip patch antenna is calculated, as shown below in Fig. 6, to be 459.77 MHz.
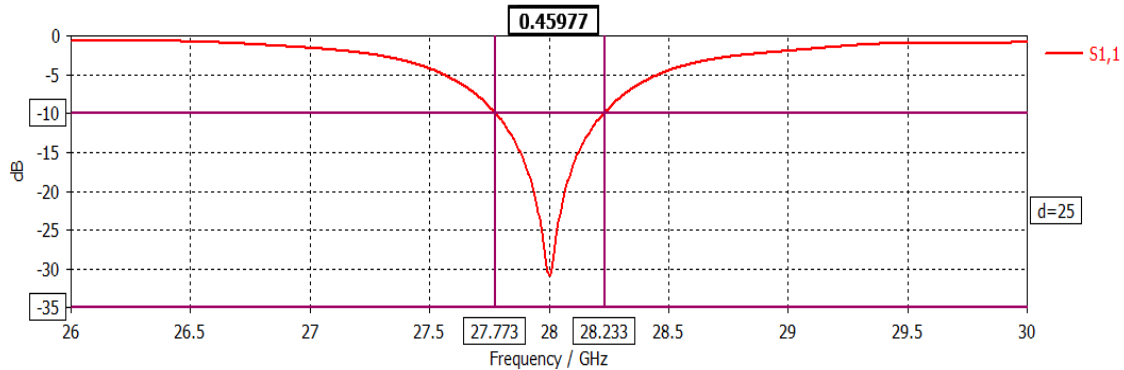

Fig. 6. Optimized bandwidth for the simulated antenna.

4.3. Gain

The microstrip patch antennas are famous for their poor gain; this is because antenna gain is affected by substrate thickness and relative dielectric constant. Where the gain is inversely proportional to the dielectric constant and directly proportional to substrate thickness [14][15]. For the designed rectangular MPA, the gain is 7 dBi, as shown in Fig. 7.
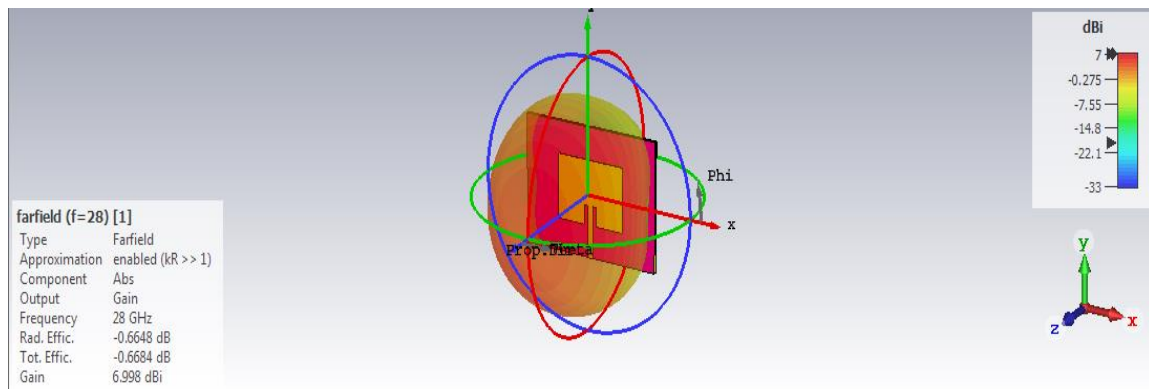

Fig. 7. Optimized gain for the simulated antenna.

5. CONCLUSION

In this paper, a rectangular microstrip patch antenna has been designed and optimized at an operating frequency of 28 GHz by using CST software. In order to obtain the best performance, the inset feeding technique has been used to feed the proposed antenna, which contributes to the best impedance matching between the source of the power and the antenna. After the optimization process had been applied, the operating frequency of 28 GHz was obtained as to the desired for this study. The results obtained from the time domain solver of the CST software were satisfactory, where the 7 dBi antenna gain and -30.5 dB return loss were achieved. In conclusion, the objectives of the study were met to obtain a compact antenna with good performance.

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BIOGRAPHY OF AUTHORS

Hamzah M. Marhoon received his B.Sc. degree in Electrical Engineering (Rank 2) from the College of Engineering Al-Mustansiriyah University, Baghdad, Iraq, in 2016. He obtained his M.Sc. degree in Communications Engineering in 2020 from Al-Ahliyya Amman University, Hashemite Kingdom of Jordan. He works as a teaching assistant at Al-Esraa University College, Baghdad, Iraq. His research interests include Antennas, Tuneable Antennas, IoT, Energy Harvesting Antennas, and Embedded Systems. Email: hamzaalazawy33@yahoo.com. Orcid: https://orcid.org/0000-0001-5613-6685

Noorulden Basil Mohamadwasel was born in Baghdad, Iraq November 11, 1993. He is, at present way thinking of a doctor of philosophy (Ph.D.) in Electrical and Computer Engineering, Istanbul Altinbas University, Istanbul, Turkey. He had received a Master of Science (M.Sc.) in Electrical and Computer Engineering, Istanbul Altinbas University, Istanbul, Turkey in 2019. He obtained the Bachelor of Science (B.Sc.) in Computer Techniques Engineering, Al-Esraa University College, Baghdad, Iraq in 2016. His interested area towards: Control Systems, Optimization Techniques, Autonomous Systems, Antenna Propagation, Networking and Fiber Optic and he had published more than 24 Research Article and a book and a Reviewer in 6 Journals, Editor in 2 Journals and he is currently a reviewer at Soft Computing journal.

Hussein A. Abulnabi received his B.Sc. degree in Electrical and Electronic Engineering from Military Engineering College, Baghdad, Iraq, in 1991. He obtained his M.Sc. degree in Electronics and Communication Engineering in 2000 from AL- Mustansiriyah University. He received his Ph.D. degree in Communication Engineering in 2017 from the University of Technology. He works as an Assoc. Prof. at AL-Mustansiriyah University, College of Engineering, Baghdad, Iraq. His research in Tunable Antenna, Terahertz antennas, Graphene, and Artificial Magnetic conductors. E-mail: husseinali@uomustansiriyah.edu.iq. Orcid: https://orcid.org/0000-0002-2156-2710

Ahmed R. Ibrahim received his B.Sc. degree in Computer Science from Al-Rafidain University College, Baghdad, Iraq, in 2015. He obtained his Master of Science (M.Sc.) in Information Technologies at Istanbul Altinbas University, Istanbul, Turkey, in 2019. He works as an assistant lecturer at Al-Esraa University College, Baghdad, Iraq. His interested area that including Optimization Techniques, Image Recognize, Modelled Systems.