Available online at www.garmian.edu.krd

Passer Journal

Passer 4 (Issue 2) (2022) 100-104

http://passer.garmian.edu.krd/

Design and Simulation of Rectangular Microstrip Patch Antennas (45 GHz and 60 GHz) for V-band Applications

Miran Hama Rahim Saeed[1*]

[1]*Information Technology Department, Computer Sciences institute, Sulaimani Polytechnic University, University of Human Development, Sulaimani, Kurdistan Region, Iraq*

Received 09 March 2022; revised 30 June 2022;
accepted 19 July 2022; available online 26 July 2022

doi:10.24271/psr.47

ABSTRACT

In this article, two wideband microstrip rectangular patch antennas have been designed and simulated for V band communication systems at resonant frequencies 45 GHz and 60 GHz. Rogers RO4730G3 is used as a substrate dielectric with dielectric constant 2.98. The dimensions of the antennas are 6.23mm*6.7mm*0.7mm and 6mm*6.4mm*0.7mm respectively, with very simple geometrical configuration. To investigate the performance, the designs were then simulated using (CST) Studio Suite® software package. The dimensions have been well studied and optimized to obtain acceptable results of Voltage Standing Wave Ration (VSWR), return loss, gain, bandwidth (BW) and radiation pattern. The 45 GHz antenna provides a gain of 6.73 dBi with the BW of 5.5 GHz and 1.03 of VSWR. Meanwhile, the 60 GHz design offers 6.92 dBi of gain with BW of 11.57 GHz and 1.05 of VSWR. The achieved results illustrate that both designs provide a good performance and are applicable for future 5G communication systems or any applications in the V band region.

Keywords: Microstrip Patch Antenna, V-band, 5G, 45 GHZ Patch Antenna, 60 GHz Patch Antenna.

1. Introduction

Microstrip patch antenna (MPA) or printed antenna plays a key role in today's wireless communication systems. Ease of fabrication on printed circuit board, low cost, different shape designs, small in size and lightweight are the most significant distinguishes of microstrip patch antenna[1,2]. The forementioned advantages and many mores made patch antenna suitable for wide varieties of applications such as biomedical devices, satellite communications, spacecraft communications, cellular phones, internet of Things (IOT) devices, and lastly in 5G communications[2–7]. V band frequency ranges start from 40 GHz to 75 GHz of millimeter wave band (3 GHz to 300 GHz)[8]. In parallel with the allocation of 45.5-47 GHz, 47.2-48.2 and 66-71 GHz bands for 5G deployments in World Recommendation Conference (WRC-19) International Telecommunication Union (ITU)[9], recent trends show numerous researches in proposing high-performance microstrip patch antenna in V band frequencies and other bands of millimeter waves for 5G communication systems and other applications[3-7],[10–14]. The foucses of many researches are to optimize the antenna to deliver optimum performance, this is some how achived by serveral modifications of antennas' shape, while the geomerty of the shape is getting very complicated and impractical for fabrication and manufacturing. This research aims to reach optimum performance of two microstrip patch antennas at V bands frequencies, while keep the geometry of the antenna very simple.

* Corresponding author
E-mail address: miran.saeed@spu.edu.iq(MSc).
Peer-reviewed under the responsibility of the University of Garmian.

2. Literature Review

This section provides a comprehensive review of state of the art of related works. Having developments in wireless technologies and their applications in conjunction with the simplicity and affordability of microstrip patch antenna, made a huge number of researches to be carried out in this area.

A wideband rectangular patch with three circular etched and a U-shaped etched were proposed, resonating at central frequencies 65 GHz and 72.5 with BW of 11.2 GHz operating from 63 GHz to 74.2 GHz, the achieved gain was 10.2 dBi and 9.6 dBi at central frequencies respectively[3]. However, the proposed design has a very difficult geometry. A Dual-band dual-patch rectangular antenna at operating frequencies 38 GHz - 60 GHz for 5G mobile headsets simulated and fabricated for experimental purposes in[4]. The gain of the designed antenna is 6.5 dBi and 5.5

dBi respectively, the measured BWs of the fabricated antenna for both upper and lower frequencies are much higher compared to the result of the simulation. Furthermore, the proposed antenna is not suitable for high BW requirements. A prototype of conventional dual-band circular patch with several modifications designed for V-band communication, operating at resonant frequency 65 GHz, with high gain 10.3 dBi and ultra wide BW 16.1 GHz[10]. Although introducing the three elliptical patches increased BW, it made the geometry of the patch much more complicated. In[11], a circular dual-band patch antenna with elliptical etched has been presented for 5G mobile applications. The antenna operates at center frequencies 28 GHz and 45 GHz with BW of 1.3 GHz and 1 GHz, respectively. In order to achieve higher gain, which is required for mobile communications, the authors of[11] have introduced 1*4 elements array, which results 12 dBi of gain and one more resonant frequency at 34 GHz. Despite of achieving the targeted gain, the BW s of the resonating frequencies are low. A single band rectangular patch antenna with center frequency, BW and gain 38 GHz, 1.021 GHz, 5 dBi, respectively, have been proposed. Despite of low gain, compared to the forementioned designs, the substrate thickness and dielectric constant are obviously greater[12]. In[13], an interesting dual-band compact patch has been presented, the antenna operates at 28.2 GHz and 42 GHz. The result of return loss and VSWR graphs shows that the lower band has 2 GHz of BW and the upper band has 9.2 GHz of BW.

3. Rectangular Microstrip Patch Antenna Design

In this section, all the required theories behind the design of rectangular patch antenna will be explained. First of all, the patch antenna is made up of three successive layers: patch or the radiator part at the top, then a dielectric substrate, the ground plane is then at the bottom. The patch and the ground plane are made up of conductor material such as copper. Figure (1) illustrates the geometry of the rectangular patch antenna.

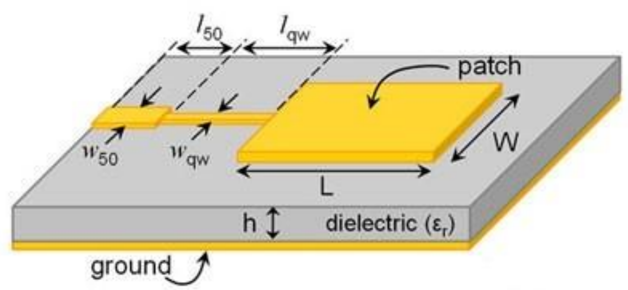

Figure 1: Geometry of Rectangular Microstrip Patch Antenna with Quarter Wave Length Transmission line

Source: Adapted from [15]

The initial step to develop a rectangular patch antenna is to determine the resonant frequency , type of dielectric substrate and substrate height then the following equations are used to determine the dimensions of the patch and the ground plane[1,14].

$$W = \frac{C}{2fo}\sqrt{2/(Er+1)} \quad (1)$$

$$Ereff = \frac{Er+1}{3} + \frac{Er-1}{3}\sqrt{1+12\frac{h}{W}} \quad (2)$$

$$Leff = \frac{C}{2fo\sqrt{Ereff}} \quad (3)$$

$$\Delta L = 0.412h\frac{(Ereff+0.3)(\frac{W}{h}+0.264)}{(Ereff-0.258)(\frac{W}{h}+0.8)} \quad (4)$$

$$L = Leff - 2\Delta L \quad (5)$$

$$Lg = L + 6h \quad (6)$$

$$Wg = W + 6h \quad (7)$$

Where

W: Width of the patch

Er: Dielectric constant

$Ereff$: Effective dielectric constant

fo: Resonant frequency

h: Dielectric substrate height

$Leff$: effective length

ΔL: Extension of the patch length

L: Length of the patch

Lg: length of the dielectric substrate and ground plane

Wg: width of the dielectric substrate and ground plane

After that, a proper impedance matching technique is required to feed the antenna. Quarter wavelength transmission line can be used with V band frequencies. Due to the fact that almost all transmission lines and microwave sources are manufactured with 50 Ω as a standard[16], the focus will be on 50 Ω transmission line feeding method in this work.

In the beginning, the impedance of the edges of the patch needs to be calculated using the following equation

$$Za = \left(\frac{L}{w}\right)^2 90\,\frac{Er^2}{Er-1} \quad (9)$$

Then the input impedance of the transmission line Zin is set at 50 Ω, the width W_{50} depends on the operating frequency and substrate constant and height. The impedance of the quarter waver length Zqw then can be calculated using the following formula.

$$Z_{qw} = \sqrt{Z_{in}Z_a} \quad (10)$$

The width of quarter wavelength W_{qw} can be computed based on it is impedance Z_{qw} , resonant frequency, dielectric constant and height, the length of quarter wavelength l_{qw} then can be calculated using the following equation[16]

$$l_{qw} = \frac{\lambda}{4\sqrt{Ereff}} \quad (11)$$

4. Proposed Antennas Design

The design process initiates with determining the resonant frequency, substrate height and substrate material. Then equations (1) to (11) are used to compute the dimensions of the antenna and the transmission line. After the initial calculation of all the parameters, (CST) Studio Suite® software package has been used to simulate the proposed designs. In order to get optimum results of VSWR, gain, return loss and bandwidth, the values of the dimensions are tuned, and the simulation has been run several times to reach the acceptable performance compared to the literature. Table (1) illustrates the optimized values of the parameter

Table 1: Tuned values of the antennas design parameters.

Parameters	Values	
Resonant Frequency (Fo)	45 GHz	60 GHz
Dielectric Substrate	Rogers RO4730G3	Rogers RO4730G3
Dielectric constant (Er)	2.98 mm	2.98 mm
Substrate height (h)	0.7 mm	0.7 mm
Width of the patch (W)	2.35 mm	1.4 mm
Length of the patch (L)	1.5 mm	1.15 mm
length of the dielectric substrate (Lg)	6.23 mm	6 mm
Width of the dielectric substrate (Wg)	6.7 mm	6.4 mm
The thickness of patch and ground plane (t)	0.08 mm	0.08 mm
Width of quarter wavelength (Wqw)	0.55 mm	0.75 mm
Length of quarter wavelength (Lqw)	1.09 mm	0.839 mm
Width of input transmission line (W50)	1.8 mm	2.25 mm
Length of input transmission line (l50)	1.5 mm	1.6 mm

5. Simulation Results and Discussion

In this section, the results of the simulation are illustrated and discussed. The most important key metrics or factors are used to evaluate the designed antennas' performance which are VSWR, return loss (S11), BW, Two Dimensions (2D) radiation pattern and Three Dimensions (3D) radiation pattern and finally, the gain of the antennas.

5.1 Result of 45 GHz Antenna Design

In figure (2), it can be seen that the VSWR of the proposed antenna is about 1.03, which is quite comparable to the ideal status. In general, VSWR shows how well the transmission line impedance match with the input impedance of the antenna. In order for an antenna to perform well, the return loss S11 should be less than -10 dB which means nearly 10% of the input power is wasted or returned back to the source[11,1]. Figure 3 shows that, the S11 is -36 dB at 45 GHz, which means almost all of the input power is radiated. From S11 graph, the BW of the antenna can be computed at the range of -10 dB of S11 between lower frequency and upper frequency of the resonant frequency, which is about 5.5 GHz.

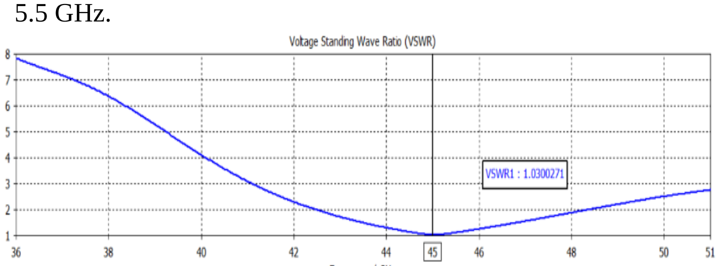

Figure 2: VSWR of 45 GHz Design.

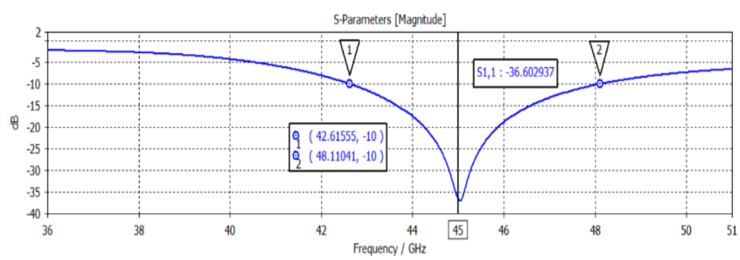

Figure 3: Return loss of 45 GHz Design.

In terms of the radiation pattern, Figure (4.a, 4.b) illustrates the 2D and 3D radiation patterns of the proposed patch antenna at 45 GHz. In order to make the direction of the radiation pattern much clear, the structure of the antenna is added to the 3D pattern. It can be observed that, the radiated power is vertically directed with a gain of 6.73 dBi at 45 GHz in the same direction. In addition, two side lobes can be noticed with significantly low power.

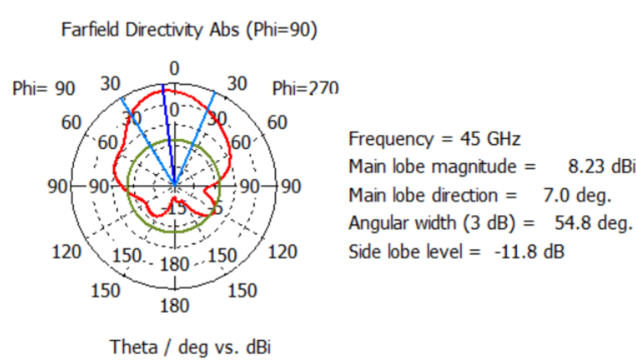

Figure 4.a: Two dimensions radiation pattern of 45 GHz design.

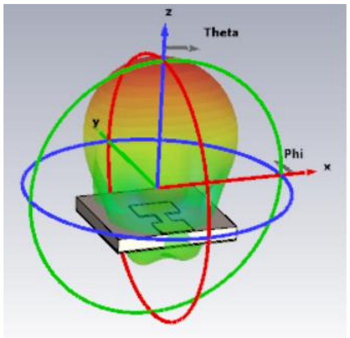

Figure 4.b: Three dimensions radiation pattern of 45 GHz design.

5.2 Result of 60 GHz Antenna Design

The simulation result of VSWR for 60 GHz design illustrates in Figure (5), the ratio reaches a minimum and acceptable value at the resonant frequency, which is 1.05. Therefore, in terms of VSWR the proposed design performs well. Compared to the result of 45 GHz design, the BW of the 60 GHz Design is much greater which is 11.57 GHz. Furthermore, the return loss at the intended frequency is -31.63 dB. Figure (6) shows the return loss of 60 GHz suggested Design.

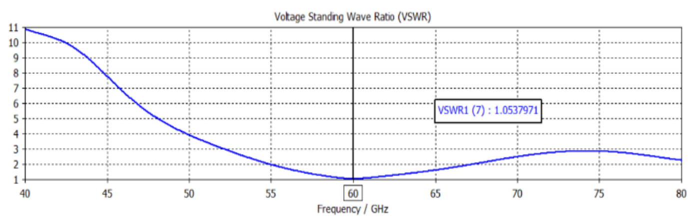

Figure 5: VSWR of 60 GHz Design.

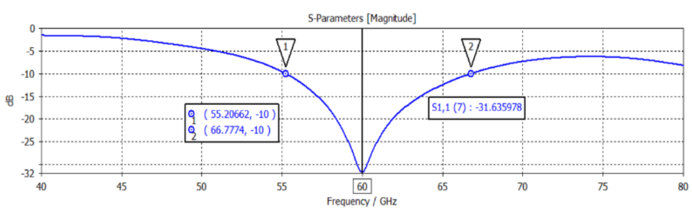

Figure 6: Return loss of 60 GHz Design.

The Fairfield directivity or the radiation pattern of 60 GHz Design illustrates in Figure (7.a, 7.b). It can be seen that the antenna has a good gain with a magnitude of 6.92 dBi to ward vertical direction of the antenna and is almost greater compared to 45 GHz design. In contrast, there is higher power radiated in the side lobes compared to the 45 GHz design

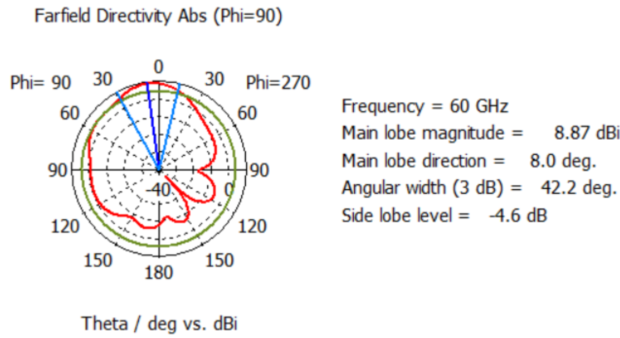

Figure 7.a: Two dimensions radiation pattern of 60 GHz design.

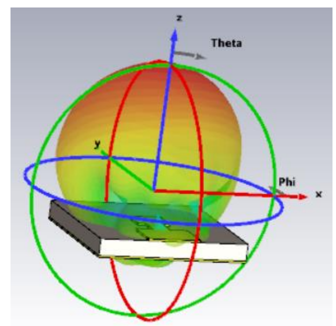

Figure 7.b: Three dimensions radiation pattern of 60 GHz design.

6. Evaluation

Compared to the state of the art of related works which is shown in Table 2, the proposed designs provide a good performance in terms of size, which is very important for hand set devices. In addition, the geometry of the designs is very simple for fabrication. Furthermore, the recommended designs provide high BW which meets 5G applications and demand-based requirements. While both of the designs, deliver acceptable gains.

Table 2: comparison of the proposed designs with published works.

Ref	Central Frequency (GHz)	Band Width (GHz)	Gain (dBi)	Dimensions (L*W*h) (mm*mm*mm)	Er – Dielectric types	Design Technique (Band – elements)
[3]	65 - 72.5	11.2	10.2 - 9.6	12*13*0.508	2.2 - Duriod 5880	Two Resonant Frequencies)-Single
[4]	38 - 60	2 - 3.2	6.5 - 5.5	15*25*0.25	3.0-Rogers RO3003	Dual-Dual
[10]	65	16.1	10.3	12*13*0.508	2.2-Rogers RT5880	Patch antenna with fractal structure and slot – single
[11]	28 - 45	1.3 - 1	7.6 – 7.2	6*6*0.578	2.2-Rogers RT5880	Dual – Single
[12]	38	1.021	5	6.1*11*1.6	4.4 - FR4	Single –Single
[13]	28.2 - 42	1.7 – 11	6.12 – 6.21	8*8*0.8	3.66-Rogers RO4350	Double – Single
Suggested 45GHz Design	45	5.5	6.73	6.23*6.7*0.7	2.98-Rogers RO4730G3	Single-Single
Suggested 60GHz Design	60	11.57	6.92	6 *6.4*0.7	2.98-Rogers RO4730G3	Single-Single

7. Conclusion

In this paper, two single element – single band rectangular patch antennas for V-band applications have been presented. The patches are designed on Rogers RO4730G3 substrate with a height of 0.7 mm. The antennas resonate at 45 GHz and 60 GHz frequencies. After the initial design, during simulation processes, the dimensions are optimized to reach peak performance in term of size, VSWR, BW and gain. Both of the designs intended to connect to 50 Ω input impedance. The results show that, the 60 GHz design provides better performance of BW and gain with 11.57 GHz and 6.92 dBi, respectively. Moreover, in comparison to the related works, the proposed designs have the simplest geometry and are small in size despite providing high BW and acceptable gain.

Conflict of interests

None.

References

[1] C. A. Balanis, Antenna theory: analysis and design (4th ed). John wiley & sons, 2015.

[2] K. F. Lee, K. M. Luk, and H. W. Lai, Microstrip patch antennas. World Scientific, 2017.

[3] M. Hussain, S. M. Rizvi, A. Abbas, A. Nadeem, I. Alam, and A. Iftikhar, “A Wideband Antenna for V-Band Applications in 5G Communications,” in 2021 International Bhurban Conference on Applied Sciences and Technologies (IBCAST), 2021, pp. 1017–1019.

[4] M. H. Sharaf, A. I. Zaki, R. K. Hamad, and M. M. Omar, “A novel dual-band (38/60 GHz) patch antenna for 5G mobile handsets,” Sensors, vol. 20, no. 9, p. 2541, 2020.

[5] G. Arora, P. Maman, A. Sharma, N. Verma, and V. Puri, “Systemic overview of microstrip patch antenna’s for different biomedical applications,” Advanced Pharmaceutical Bulletin, vol. 11, no. 3, p. 439, 2021.

[6] W. M. Abdulkawi, A. F. A. Sheta, I. Elshafiey, and M. A. Alkanhal, “Design of Low-Profile Single-and Dual-Band Antennas for IoT Applications,” Electronics, vol. 10, no. 22, p. 2766, 2021.

[7] S. Riaz, M. Khan, U. Javed, and X. Zhao, “A Miniaturized Frequency Reconfigurable Patch Antenna for IoT Applications,” Wireless Personal Communications, pp. 1–11, 2021.

[8] G. Kizer, Digital microwave communication: engineering point-to-point microwave systems. John Wiley & Sons, 2013.

[9] M. J. Marcus, “ITU WRC-19 spectrum policy results,” IEEE Wireless Communications, vol. 26, no. 6, pp. 4–5, 2019.

[10] M. Hussain, S. I. Naqvi, W. A. Awan, W. A. E. Ali, E. M. Ali, S. Khan, and M. Alibakhshikenari, “Simple wideband extended aperture antenna-inspired circular patch for V-band communication systems,” AEU-International Journal of Electronics and Communications, vol. 144, p. 154061, 2022.

[11] M. I. Khattak, A. Sohail, U. Khan, Z. Barki, and G. Witjaksono, “Elliptical slot circular patch antenna array with dual band behaviour for future 5G mobile communication networks,” Progress In Electromagnetics Research C, vol. 89, pp. 133–147, 2019.

[12] C. Seker and muhammet Guneser, “A single band antenna design for future millimeter wave wireless communication at 38 GHz,” European Journal of Engineering and Formal Sciences, vol. 2, no. 2, pp. 1–5, 2019.

[13] K. Ullah, S. Ullah, I. ud Din, T. Mahboob, A. R. Mashal, S. Ullah, and U. Habib, “Design and Analysis of a Compact Dual-Band Patch Antenna for 5G mmW Application,” in 2020 14th International Conference on Open Source Systems and Technologies (ICOSST), 2020, pp. 1–5.

[14] S. Subramanian, S. K. Selvaperumal, V. Jayapal, and R. M. T. Abdulla, “Multiband high gain microstrip patch antenna at ka band (26 ghz),” Journal of Advanced Research in Dynamical and Control Systems, 2019.

[15] “Microstrip Patch Antenna,” EM Talk. [Online]. Available: https://emtalk.com/. [Accessed: 07-March-2022].

[16] R. Rizhi and S. Sharma, “Impedance Matching Techniques for Microstrip Patch Antenna,” Indian Journal of Science and Technology, vol. 10, no. 28, 2017.