https://doi.org/10.26682/sjuod.2020.23.2.35

Journal of University of Duhok, Vol.23, No.2 (Pure and Eng. Sciences), Pp 430-438, 2020 (Special Issue)

DESIGN OF RECTANGULAR-SHAPED MICROSTRIP PATCH ANTENNAS FOR MILLIMETER WAVE BANDS

RAWAZ HUSSAIN ABDULLAH[1] and KAWAN FAIQ AHMED
[1]Technical College of Engineering, Sulaimani Polytechnic University , Kurdistan Region-Iraq

(Accepted for Publication: December 8, 2020)

ABSTRACT

This study presents the design and simulation of two separate rectangular shaped microstrip patch antennas to operate at 38 GHz and 50 GHz millimeter wave (mmWave) bands, using high-frequency structure simulator (HFSS) software package. The work mainly underlines the importance of utilizing a dialectic substrate from ROGRES Corporation. The substrate is used in the design of the proposed antennas, and is made up of hydrocarbon ceramic laminates, known as the RO4350B. The influence of the dielectric material has been studied on the performance of the antennas, like return loss, voltage standing wave ratio (VSWR), antenna bandwidth, antenna gain, and radiation pattern. The obtained 38 GHz antenna has about 8.06 dBi of gain and a 4.01 GHz of bandwidth with a return loss of less than -10dB from 35.23 GHz to 39.24 GHz. On the other hand, the 50 GHz antenna provides a 5.1 dBi of gain with much higher bandwidth (up to 7.2864 GHz) starting from 47.1106 GHz to 54.397 GHz. Beside these remarkable features, the thickness of the selected substrate is 0.762 mm. Both antennas might be used in future 5G wireless communication systems and short-range systems such as machine-to-machine (M2M) and device-to-device (D2D) to fulfill the necessities of wide-bandwidth, high-gain, low-weight, cheap, and easy fabrication.

KEYWORDS: Microstrip patch antenna; high-frequency structure simulator (HFSS); millimeter wave (mmWave); dielectric substrate.

1. INTRODUCTION

Millimeter wave bands starting from 3 GHz up to 300 GHz are proposed to be used in the next generation 5G wireless systems, since it will provide much higher bandwidth in comparison to the current existing systems and as a result it can enhance the transmission data rate. With the increase in bandwidth, the system capacity will also be increased, while the latency will be reduced, which give rise to better internet based access and applications like real time streaming for individual users especially in densely populated areas (Zhouyue & Farooq, 2011; Akhil & Rakesh, 2015). Generally microstrip antennas are commonly used in contemporary wireless systems due to their low-profile, low cost, easily fabricated, and portability (Balanis, 2005; Kraus & Marhefka, 2002; Behera & Barad, 2015),. Moreover, some unique characteristics of antennas are required such as high-gain and wide-bandwidth, and proper radiation features for specific applications in modern communication systems (Mishra, Singh, Singh, Singh, & Singh, 2018). Because of their fantastic properties, many efforts have been done on the analysis, design, and implementations of microstrip antennas.

A simple design of Ku-band microstrip patch antenna, which underlies the mmWave bands, has been proposed in (Bhadouria & Kumar, 2014). A number of U shaped and semi U shaped

---

rawaz.abdullah@spu.edu.iq; kawan.ahmed@spu.edu.iq

[1] Corresponding author: Technical College of Engineering, Sulaimani Polytechnic University, Kurdistan Region, Iraq

slots on patch are introduced to improve the return loss and bandwidth of the proposed antenna, thereby; a bandwidth of 1.24 GHz is achieved in the range of (15.27-16.51) GHz, and a VSWR of 1.1 is observed at resonant frequency. The FR-4 dielectric substrate with a thickness of 1.07 mm and dielectric constant of 4.9 is used. In (Haraz, Ashraf, & Alshebeili, 2015), three-element single-band printed inverted F-antenna is designed on air substrate of thickness of 0.3214 mm that operates in the 28 GHz mm-Wave band for the future 5G wireless communication systems. The corresponding each element gain is 6.06, 5.18, and 5.50 dBi, and the operating frequency was (27.73-to-28.54) GHz which provides a bandwidth of 810 MHz. A design and simulation of 28 GHz and 38 GHz dual-band millimeter wave antenna with circular polarization for 5G systems has been presented in (Aliakbari, Abdipour, Mirzavand, Costanzo, & Mousavi, 2016). The antenna is practically implemented on a 0.254 mm RT/Duroid 5880 substrate with a dielectric constant of 2.2. A maximum gain of 4 dBi with 850 MHz of bandwidth (from 29.25 GHz to 30.1 GHz) is observed at the first band. Similarly, a maximum gain of 4.5 dBi with 750 MHz of bandwidth (from 36.25 GHz to 37 GHz) is measured at the higher band. It is obvious form the results, that some shifts in the desired frequency of operation are observed during the practical measurements. The study conducted in (Wang, Mu, Wang, Safavi-Naeini, & Liu, 2017) four-pairs of microstrip multiple-input multiple-output (MIMO) antennas have been designed. The dielectric substrate RT/duroid5880 is selected with a height of 0.5 mm and relative dielectric constant of 2.2. At first, a single patch element is designed and simulated using HFSS, based on the results the operation frequency rages from 33.88 GHz to 36.12 GHz, which provides a 2.24 GHz of bandwidth and also a gain of 7.93 dBi is obtained. Then, with the aid of eight-element microstrip Taylor antenna array with series-feeding a reduction of sidelobs and increment of bandwidth (3.85 GHz) are obtained. The center frequency of the designed antenna array is 35GHz with 10 dBi of gain. Another recent study (Rahayu, Fitria, Hakiki, & Kurniawan, 2018) proposed a dual-band 8-element based array antenna for 5G applications. The elements formed in a 2 by 4 square configuration to operate in 28 GHz and 38 GHz mmWave bands. The 0.254 mm RT/Duroid 5880 substrate with a dielectric constant of 2.2 is used. Each single element is fed with a microstrip line to operate in the dual bands, a bandwidth of 1.219 GHz and 1.42 GHz are obtained at the 28 GHz and 38 GHz center frequencies, respectively. The maximum achievable gain at each band is 6.934 dBi and 7.833 dBi, respectively. The 8 elements are connected to configure a 2x4 phased array; in this case a higher gain of 15.9 dBi at 28 GHz and 16.7 dBi at 38 GHz are obtained using waveguide port as feeder.

In this work, an attractive design of a microstrip antenna has been proposed and analyzed by applying the RO4350B substrate with a thickness of 0.762 mm. The dielectric substrate consists of hydrocarbon ceramic laminates which is used in the design of two different single-microstrip patch antennas to operate in the 38 GHz and 50 GHz mmWave bands. The chosen substrate has the advantage of less weight, smaller size, and less dielectric loss because of its thin height or thickness. In spite of these interesting points, the designed antennas have satisfactory results in bandwidth, gain and VSWR and almost the same or even outperforms compared to the previous related works. Following this introductory part, the rest of the paper is organized as follows: section 2 presents the initial design and optimized parameters of the proposed antennas, and Section 3 covers the simulation results of the designed antennas with comparison with some related works. Finally, the summary of the paper are presented in section 4.

rawaz.abdullah@spu.edu.iq; kawan.ahmed@spu.edu.iq

[1] Corresponding author: Technical College of Engineering, Sulaimani Polytechnic University, Kurdistan Region, Iraq

2. ANTENNA DESIGN

Patch antennas are made up of three layers which are a rectangular ground plane at the bottom, a dielectric substrate in the middle, and the patch on the top. Both of the ground and the patch layers are made of conductors such as copper. Both of the dielectric material and the ground plane having the same dimensions. While many patch antenna shapes has been implemented and studied, rectangular and circular configurations are the most preferred in practice, because of their incredible radiation characteristics (Ahmed, Abdullah, & Abdalla, 2017; Kraus & Marhefka, 2002). The schematic diagram of the proposed antenna as well as the design parameters are illustrated in Figure 1.

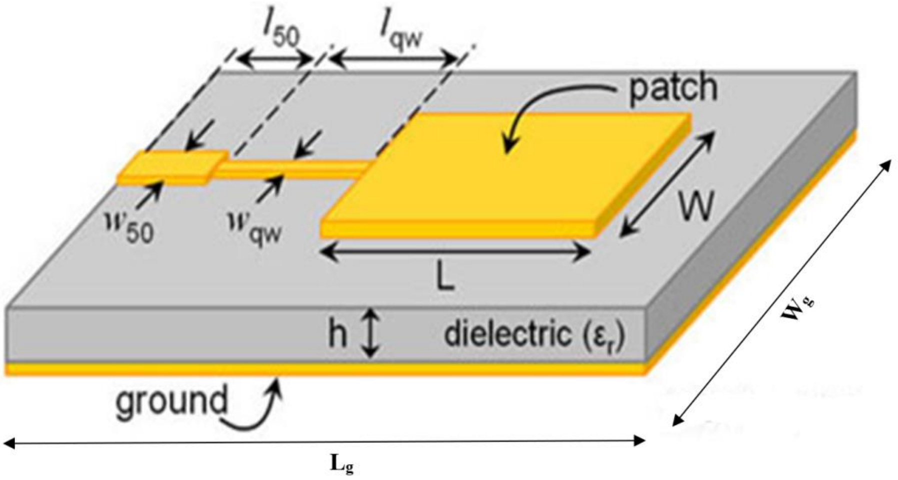


Fig. (1): Schematic diagram of the proposed antenna

Dimensions of the antenna closely related to the operating frequency and the type of the dielectric substrate. The following equations are used to compute the dimensions (width and length) of a rectangular shaped patch antenna (Balanis, 2005):

$$W = \frac{1}{2f_o\sqrt{\varepsilon_o\mu_o}}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

$$\varepsilon_{r_{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\sqrt{1 + 12\frac{h}{W}} \tag{2}$$

$$L = L_{eff} - 0.824h\frac{\left(\varepsilon_{r_{eff}} + 0.3\right)(\frac{W}{h} + 0.264)}{(\varepsilon_{r_{eff}} - 0.258)(\frac{W}{h} + 0.8)} \tag{3}$$

$$L_{eff} = \frac{1}{2f_o\sqrt{\varepsilon_{reff}}\ \sqrt{\varepsilon_o\mu_o}} \tag{4}$$

$$W_g = W + 6h \tag{5}$$

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

rawaz.abdullah@spu.edu.iq; kawan.ahmed@spu.edu.iq

[1] Corresponding author: Technical College of Engineering, Sulaimani Polytechnic University, Kurdistan Region, Iraq

Where,

W: is the patch width, and L is the length of the patch.

f_o: is the resonant frequency

$\frac{1}{\sqrt{\varepsilon_o \mu_o}}$: is the speed of light

ε_r: is the dielectric constant, and $\varepsilon_{r_{\text{eff}}}$ is the effective dielectric constant

h: is the width or height of the dielectric substrate

L_{eff}: is the effective patch length

W_g: is the width of ground plane, and L_g: is the length of the ground plane

Firstly, the initial or approximate dimensions of each antenna are computed using the design equations given in (1) to (6). The first antenna operates at 38 GHz and the other is designed to operate at 50 GHz. The RO4350B is chosen to be used as the substrate having a thickness of 0.762 mm and a dielectric constant of 3.66. The designed antennas have been simulated using high-frequency structure simulator (HFSS), version 13.0.0. During the simulation process, the initial computations of the dimensions of each designed antennas are modified to acquire optimum performance in terms of the radiation patterns, VSWR, bandwidth, and antenna gain. The optimized design parameters for the proposed antennas are given in Table 1. Among many different feeding techniques, in this study the feed line method is chosen to be used for feeding the antennas.

Table (1): Parameters for the proposed antennas

	38 GHz Design	**50 GHz Design**
Operating frequency, f_o	38 GHz	50 GHz
Substrate height, h	0.762 mm	0.762 mm
dielectric constant, ε_r	3.66	3.66
Patch length, L	1.64 mm	1 mm
Patch width, W	2.59 mm	1.8 mm
Substrate length, L_g	8.37 mm	6.23 mm
Substrate width, W_g	9.05 mm	5.8 mm
W_{qw}	0.466 mm	0.6 mm
l_{qw}	1.219 mm	0.926 mm
l_{50}	2.1 mm	1.62 mm
W_{50}	2.1 mm	1.4 mm

3. SIMULATION RESULTS

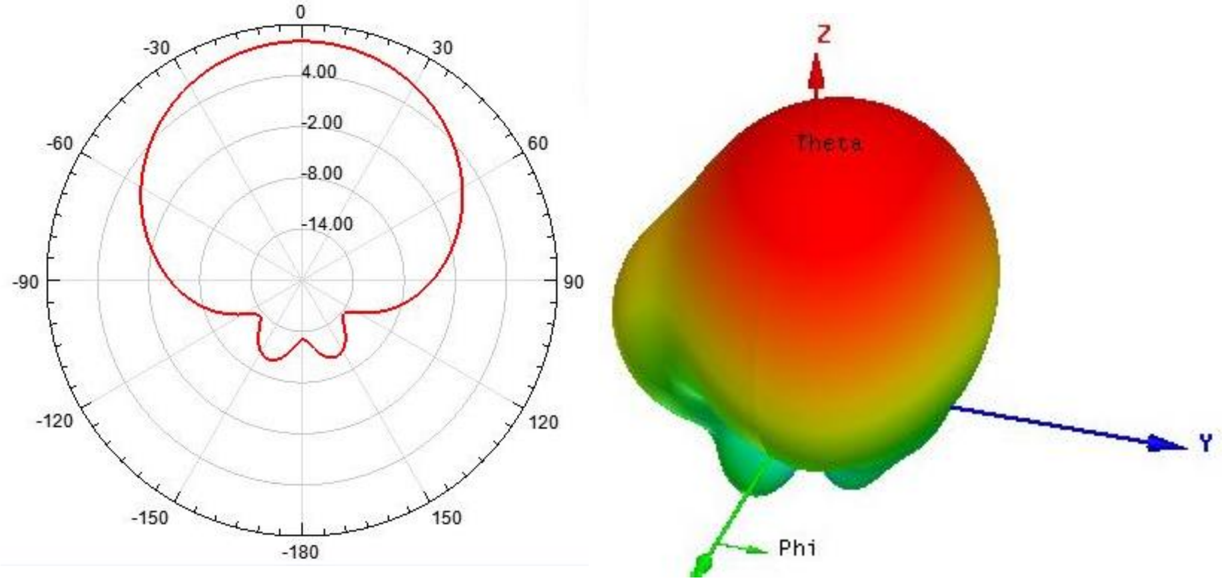
In this section, the performances of the proposed antennas are investigated by measurements of the obtained radiation patterns, realized gains, return loss, and VSWR. Several results from other related works are also presented in for the sake of comparison, such as antenna bandwidth, gain, substrate type with its thickness, and antenna configuration.

3.1 Results of the 38 GHz Antenna

The simulation of the radiation pattern or the far-field directivity of the designed antenna at 38 GHz is illustrated in Figure 2. It can be noticed that the simulated antenna mostly radiates in the direction of the observer which is the vertical direction. This agrees with the theoretical radiation pattern for these types of antennas. The antenna has a gain of 8.06 dBi in the direction of the observer.

rawaz.abdullah@spu.edu.iq; kawan.ahmed@spu.edu.iq

[1] Corresponding author: Technical College of Engineering, Sulaimani Polytechnic University, Kurdistan Region, Iraq

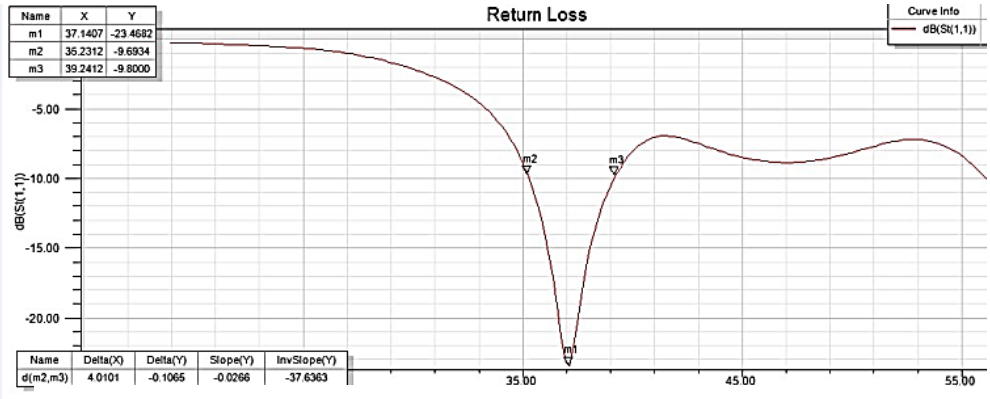


(a)

(b)

Fig. (2): Radiation pattern of the 38 GHz antenna (a); (a) 2D pattern, (b) 3D pattern.

The obtained return loss as a function of frequency for the 38 GHz antenna is shown in Figure 3. The return loss of the antenna is -23.47 dB at 37.14 GHz. It can be observed that, the actual acquired bandwidth, which is computed with the intersection of the curve with -10 dB of the return loss, is ranges from nearly 35.23 GHz to 39.24 GHz. Therefore, bandwidth of the antenna is about 4.01 GHz. Therefore, the antenna bandwidth is 10.55% of the center frequency.



Name	X	Y
m1	37.1407	-23.4682
m2	35.2312	-9.6934
m3	39.2412	-9.8000

Name	Delta(X)	Delta(Y)	Slope(Y)	InvSlope(Y)
d(m2,m3)	4.0101	-0.1065	-0.0266	-37.6363

Fig. (3): Return loss versus frequency of the proposed 38 GHz antenna

As it can be depicted in Figure 4, the VSWR of the designed patch antenna approaches to 1.437 at 38.0955 GHz which shows that the antenna well operates in the frequency band of interest.

---

rawaz.abdullah@spu.edu.iq; kawan.ahmed@spu.edu.iq
[1] Corresponding author: Technical College of Engineering, Sulaimani Polytechnic University, Kurdistan Region, Iraq

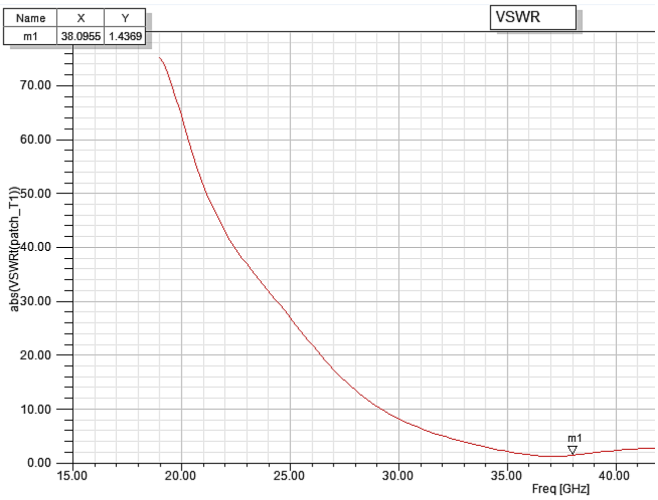
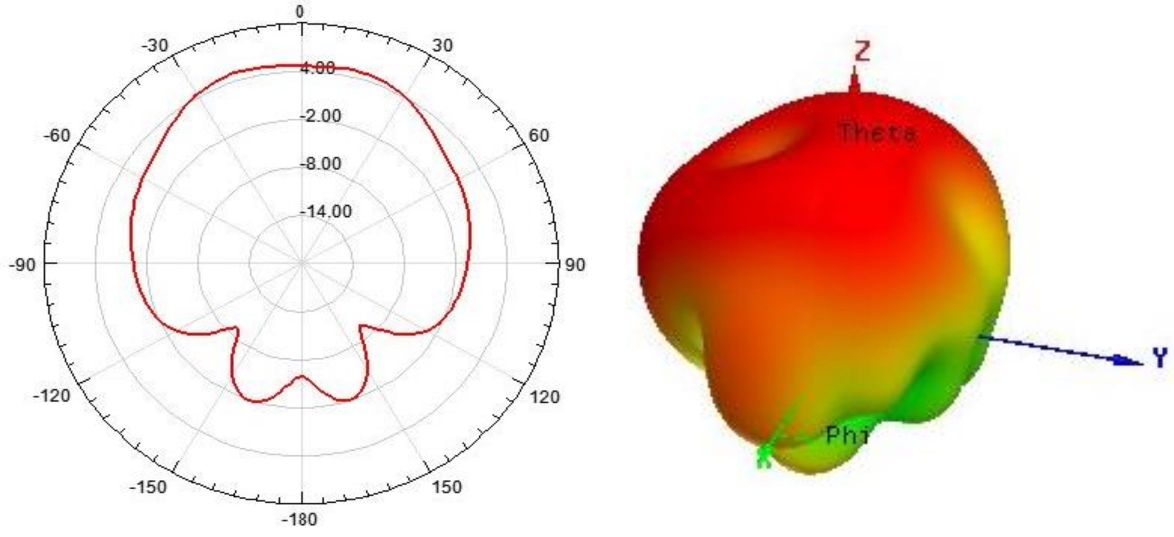


Fig. (4): VSWR versus frequency of the designed 38 GHz antenna

3.2 Results of the 50 GHz Antenna

In a similar way as demonstrated in the previous section, the 2D and 3D radiation patterns for the proposed 50 GHz antenna are shown in Figure 5. Likewise, as the previously stated, the directivity of the designed patch is in the vertical direction. For this case, the antenna gain is 5.1 dBi, which means a penalty of less than 3 dB of gain can be noticed compared to the 38 GHz design. Unfortunately, the 50 GHz antenna has wider sidelobs with slightly higher power content in the two minor-lobes in comparison to the 30 GHz design.



(a) (b)

Fig. (5): Radiation pattern of the 50 GHz antenna (a); (a) 2D pattern, (b) 3D pattern

As it can be noticed in Figure 6; the return loss of the patch is -30.48 dB at 50.377 GHz, and the frequency of operation is in the range of 47.1106 GHz to 54.3970 GHz. The antenna bandwidth is 7.2864 GHz, which is higher than the bandwidth of the 38 GHz antenna. In this case, the antenna bandwidth is around 14.573% of the resonant frequency.

As illustrated in Figure 7, the VSWR of the 50 GHz antenna is about 1.064 at 50.1256 GHz, which is quite comparable or consistent to the ideal value of VSWR.

---

rawaz.abdullah@spu.edu.iq; kawan.ahmed@spu.edu.iq

[1] Corresponding author: Technical College of Engineering, Sulaimani Polytechnic University, Kurdistan Region, Iraq

Figure 6 Return loss versus frequency of the proposed 50 GHz antenna

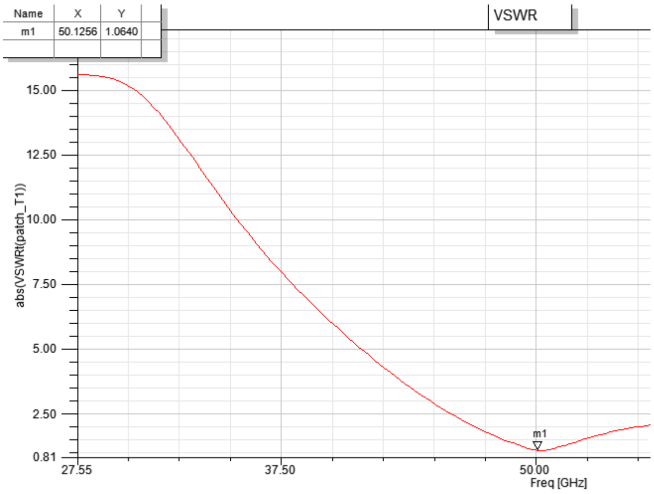


Fig. (7): VSWR versus frequency of the designed 50 GHz antenna

3.3 Comparison of the designed antennas with other designs in literature

Table 2 presents numerous antenna designs for mmWave bands that reported in literature in comparison to the proposed antennas. The performance evaluation of the antennas in terms of bandwidth and maximum attainable gain has been studied. The type of the dielectric substrate with its thickness is also presented. Finally the suggested antenna configurations are also compared in order to study the complexity of the proposed designs.

It can be noticed the proposed antennas provide wider transmission bandwidth compared to other designs. For instance, the work presented in (Wang, Mu, Wang, Safavi-Naeini, & Liu, 2017) the bandwidth is 2.24 GHz for a single-element antenna, and some improvement has been observed with 8-element array in spite of the system complexity. The 38 GHz proposed antenna provides 8.06 dBi of gain, which is better than all other single-element based designs. Although it is less than the 10 dBi gain obtained using 8-element array in (Wang, Mu, Wang, Safavi-Naeini, & Liu, 2017), also a maximum gain of 16.7 dBi is achieved in (Rahayu, Fitria, Hakiki, & Kurniawan, 2018) when an 8-element configuration (2x4 phased array) is used. In these cases the system complexity should be taken into consideration. With the exception of the work has been done in (Behera & Barad, 2015), where FR-4 substrate

rawaz.abdullah@spu.edu.iq; kawan.ahmed@spu.edu.iq

[1] Corresponding author: Technical College of Engineering, Sulaimani Polytechnic University, Kurdistan Region, Iraq

with a 1.07 mm width has been used, in other papers a narrower dielectric substrate has been selected compared to the one used in this work which is RO4350B with 0.762 mm of width, with the advantage of transmission bandwidth and gain. These remarkable results ensure the designed antennas are reliable and further enhancement in transmission gain and bandwidth can be obtained if proposed designs are used in arrays.

Table (2): comparison of proposed microstrip antennas for mmWave bands

Reference	Bandwidth (GHz)/ Operation Frequency (GHz)	Gain (dBi)	Substrate Type	Substrate Thickness (mm)	Antenna Configuration
(Bhadouria & Kumar, 2014)	1.24/(15.27-16.51)	4.45	FR-4	1.07	Single-Element
(Haraz, Ashraf, & Alshebeili, 2015)	0.810/(27.73-28.54)	6.06	Air	0.314	Triple-Element
(Aliakbari, Abdipour, Mirzavand, Costanzo, & Mousavi, 2016)	0.850/(29.25-30.1) & 0.750/(36.25-37.0)	4 & 4.5	RT/Duroid 5880	0.254	Single-Element/Dual-Band
(Wang, Mu, Wang, Safavi-Naeini, & Liu, 2017)	2.24/(33.88-36.12) & 3.85/(32.5-36.35)	7.93 & 10	RT/duroid5880	0.5	Single-Element & 8-Element Array
(Rahayu, Fitria, Hakiki, & Kurniawan, 2018)	1.219/(28.114-29.333) 1.42/(37.871-39.291) & 2.3/(27-29.3) 1.5(37.8-39.3)	6.934 7.833 & 15.9 16.7	RT/Duroid 5880	0.254	Single-Element/Dual-Band & 2x4 Phased-Array/ Dual-Band
Proposed 38 GHz Antenna	4.01/(35.23-39.24)	8.06	RO4350B	0.762	Single-Element
Proposed 50 GHz Antenna	7.2864/(47.1106-54.397)	5.1	RO4350B	0.762	Single-Element

4. CONCLUSIONS

In this work two separate microstrip antennas has been suggested for next generation systems to operate at the millimeter wave bands, for instance 38 GHz and 50 GHz. At least 4 GHz of bandwidth and 8 about dBi of gain are obtained with the 38 GHz design. The 50 GHz antenna provides a bandwidth of about 7.286 GHz and a gain of 5.1 dBi. The RO4350B substrate is proposed to be used in both designs. Although the thickness of the indicated dielectric material is slightly wider compared to the previous related works, the proposed antennas have the advantages of wider bandwidth, higher gain, and simplicity.

Therefore, the proposed antennas could be used in future wireless applications and it can be easily fabricated, with satisfactory results in antenna gain, return loss, and VSWR as they have been proven by the simulation results using the widely used HFSS simulation software package. Further improvement in bandwidth and gain can be achieved if they are used

rawaz.abdullah@spu.edu.iq; kawan.ahmed@spu.edu.iq
[1] Corresponding author: Technical College of Engineering, Sulaimani Polytechnic University, Kurdistan Region, Iraq

in arrays.

REFERENCES

-Ahmed, K. F., Abdullah, R. H., & Abdalla, D. S. (2017, August). Design and Simulation of Microstrip Patch Antenna for Wireless Applications. *Kurdistan Journal for Applied Research (KJAR), 2*(3). Retrieved from kjar.spu.edu.iq

-Akhil, G., & Rakesh, K. J. (2015, July 28). A Survey of 5G Network: Architecture and Emerging Technologies. *IEEE Access, 3*, 1206 - 1232. doi: 10.1109/ACCESS.2015.2461602

-Aliakbari, H., Abdipour, A., Mirzavand, R., Costanzo, A., & Mousavi, P. (2016). A Single Feed Dual-band Circularly Polarized Millimeter-wave Antenna for 5G Communication. *2016 10th European Conference on Antennas and Propagation (EuCAP)* (pp. 1-5). Davos, Switzerland : IEEE. doi:10.1109/EuCAP.2016.7481318

-Balanis, C. A. (2005). *Antenna Theory: Analysis and Design* (3rd ed.). New Jersey, USA: Johm Wiley & Sons.

-Behera, S., & Barad, D. (2015). A Novel Design of Microstrip Fractal Antenna for Wireless Sensor Network. *IEEE International Conference on Computation of Power, Energy Information and Communication (ICCPEIC), pp.* (pp. 470 – 474). IEEE.

-Bhadouria, A. S., & Kumar, M. (2014). Wide Ku-Band Microstrip Patch Antenna Using Defected patch and ground. *IEEE International Conference on Advances in Engineering & Technology Research (ICAETR-2014)* (pp. 1-5). Unnao, India: IEEE. doi: 10.1109/ICAETR.2014.7012794

-Haraz, O. M., Ashraf, M., & Alshebeili, S. (2015). Single-Band PIFA MIMO Antenna System Design for Future 5G Wireless Communication Applications. *11th IEEE International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)* (pp. 608-612). IEEE.

-Kraus, J. D., & Marhefka, R. J. (2002). *Antennas for all applications* (3rd ed.). NewYork: McGraw-Hill.

-Mishra, B., Singh, V., Singh, R. K., Singh, N., & Singh, R. (2018, January). A compact UWB patch antenna with defected ground for Ku/K band applications. *Microwave and Optical Technology Letters, 60*(1), 1-6. doi:10.1002/mop.30911

-Rahayu, Y., Fitria, L., Hakiki, Y., & Kurniawan, A. (2018). A New 2x4 Array Design of Dual-Band Millimeter-Wave Antenna for 5G Applications. *2018 International Workshop on Antenna Technology (iWAT)* (pp. 1-4). Nanjing, China : IEEE. doi:10.1109/IWAT.2018.8379210

-Wang, Q., Mu, N., Wang, L., Safavi-Naeini, S., & Liu, J. (2017, December 17). 5G MIMO Conformal Microstrip Antenna Design. *Wireless Communications and Mobile Computing*, 1-11. Retrieved from https://doi.org/10.1155/2017/7616825

-Zhouyue, P., & Farooq, K. (2011, June 7). An introduction to millimeter-wave mobile broadband systems. *IEEE Communications Magazine, 49*(6), 101-107. doi:10.1109/MCOM.2011.5783993

---

rawaz.abdullah@spu.edu.iq; kawan.ahmed@spu.edu.iq

[1] Corresponding author: Technical College of Engineering, Sulaimani Polytechnic University, Kurdistan Region, Iraq