Wideband Hexagonal Type Antenna Design for 5G Networks

Orçun YILDIRAN[1], Hüsnü Deniz BAŞDEMİR[2]

[1, 2]Çankaya University, Electronic and Communication Engineering Department, Eskisehir Road 29. Km Etimesgut
06790 Ankara, Turkey
orcunyildiran@gmail.com, basdemir@cankaya.edu.tr

Abstract

In this paper, hexagonal type antenna for the next generation (5G) mobile networks is proposed. Both the microstrip feed line and coaxial feed techniques are used to feed the antenna. The best feed point location for both techniques is found to achieve the highest performance. The High Frequency Structural Simulator (HFSS 12.0) is used to simulate the antenna and find out the characteristics. The antenna performance characteristics such as VSWR, return loss, radiation pattern are obtained.

1. Introduction

More than five billion devices request wireless connections, for voice, data, and other applications [1]. The existing generations of cellular networks have restrictions in providing high quality and low latency applications for wireless devices [2]. Moreover, while the demand is increasing for high data rates, there is global bandwidth shortage [1]. Therefore, 5th generation (5G) mobile communication network to take increasing attention day by day with its higher transmission rate, higher capacity, more connections and lower network latency [3].

One of the significant elements of the communication systems are antennas. Compact antennas such as patch antennas must be designed to deploy the 5G system efficiently [1]. Microstrip patch antennas are commonly used in the microwave frequency region and various applications such as radar for missiles, telemetry, global positioning systems (GPS) and mobile handheld radios or communications devices due to their several advantages [4, 5]. These advantages are high performance, low cost, light weight, small size and easy to fabricate [4]. A greater number of physical parameters such as geometrical shapes and dimension are used to characterize microstrip antennas [6].

In this study, Ka-band (26.5 – 40 GHz) is investigated for 5G communication system. For this purpose, a Ç-shaped patch antenna is designed. The proposed antenna, which is shown in Figure 1, resonate at 28 GHz and suitable for 5G communication systems. Both the microstrip feed line and coaxial feed techniques are investigated to achieve the best performance.

The antenna covers the band from 27.6 GHz to 28.5 GHz with overall bandwidth of 900 MHz for microstrip feed line technique and from 27.32 GHz to 28.84 GHz with overall bandwidth of 1.52 GHz for coaxial feed technique. The size of the proposed antenna is 10.5 mm x 10.5 mm x 0.508 mm for microstrip feed line technique and 7.5 mm x 7.6 mm x 0.508 mm for coaxial feed technique. It is designed on Rogers RT/duroid 5880 material with 2.2 dielectric constant and 0.508 mm thickness. The best location for feeding point of both feeding techniques is found by using a trial and error method. HFSS 12.0 is used to simulate and optimize the antenna.

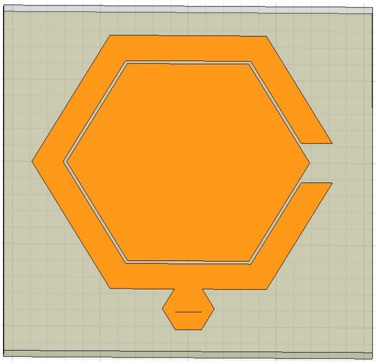


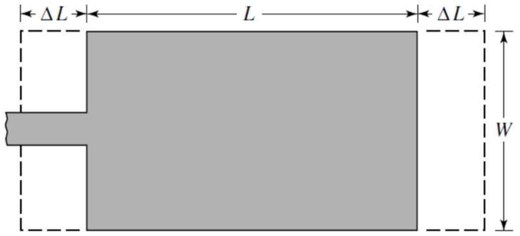
Fig. 1. The Proposed Ç – Shaped Patch Antenna

2. Microstrip Patch Antenna Design and Analyses

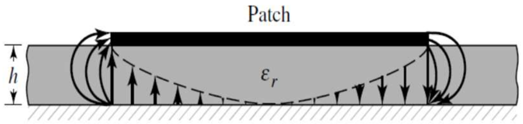
The proposed Ç-shaped patch antenna which operates at 28 GHz is shown in Fig. 1. It can be seen that, the antenna consists of a substrate that includes the ground plane, Ç-shaped and an inner hexagonal radiating patches. Several Ç-shaped patch antennas of different dimensions are designed and analyzed. The substrate dimension including the ground, dimension of the feed line which is the tail of the 'C' are changed and the effect of them are observed. Moreover, radiating patch dimensions (both inner and Ç-shaped patch) are changed to see the coupling effect and its effect on the antenna performance. Moreover, the two different type of the feeding methods (microstrip feed line and coaxial feed) are used. The effect of both feeding methods and feeding point are investigated. For the proposed antenna, as a start point, dimensions are calculated based on the following equations given by [7]. To find the patch width the formula below is used.

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{V_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (1)$$

where ε_r is dielectric constant of the substrate, f_r is the resonant frequency, μ_0 is free space permeability, ε_0 is free space permittivity and V_0 is the free space velocity. To find the length of the patch, effective dielectric constant ε_{reff} has to be calculated firstly from Eq. (2). Then, the calculated ε_{reff} value is used to calculate the ΔL which is a function of ε_{reff}. It is a parameter which is a result of fringing effects. Due to these effects, the patch of the microstrip antenna looks greater than its physical dimensions electrically. This situation is shown in Figure 2 for the E-plane (xy-plane).



(a) Top View



(b) Side View

Fig. 2. Physical and Effective Lengths of Rectangular Microstrip Patch [7]

The effective dielectric constant formula is given as

$$\varepsilon_{reff}=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2} \qquad (2)$$

where h is the height of the substrate. ΔL is given as

$$\frac{\Delta L}{h}=0.412\frac{(\varepsilon_{reff}+0.3)+(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.254)+(\frac{W}{h}+0.8)} \qquad (3)$$

As a result of fringing effects, the length of the patch is extended by ΔL. Therefore, to calculate the effective length, following formula is given.

$$L_{eff} = L+2\Delta L \qquad (4)$$

Finally, for this design the substrate and the ground plane have same dimensions. To calculate the substrate and the ground plane dimensions following formulas given by Ref. [6] and [8] are used.

$$L_g=6h+L \qquad (5a)$$
$$W_g=6h+W \qquad (5b)$$

After the calculation, the dimension of this antenna is obtained as W = 4.24 mm, L = 3.393 mm where W and L values indicates the distance from the center point to one of the polygon's vertices. The L and W values given in Eqns. (5a) and (5b) indicates the width and length of the rectangular patch antenna. To use these equations for hexagonal patch, the total width of it should be calculated. Therefore, the calculated width should be multiplied with two because it indicates the only one vertices of the hexagonal. The dimension of the ground plane will be $W_g = W_s =$ 11.528 mm, $L_g = L_s =$ 9.834 mm.

2.1. Design and Analyses of Microstrip Feed Line Method

The microstrip feed has very small width when it is compared with the patch size. The geometrical shape, dimension of the patch antenna, the properties of the substrate, the feed type and the position of the feed affect the input impedance.

It is easy to match the input impedance by controlling the inset position of the microstrip feed line. Moreover, the fabrication of the microstrip feed line is easy [7]. Both surface waves and spurious feed radiation increase when the substrate thickness increases [1]. To find the best feeding position for the proposed antenna with microstrip feed line, a trial and error method is used.

Firstly, the values calculated by Eqs. (1), (4), (5a) and (5b) are used to simulate the antenna. Due to the regular hexagon shape of the logo of Çankaya University, calculated values are used one by one and looked for the best result. Finally, the position of the feed point is investigated. When the antenna is fed from the bottom of the tail of 'C' which is considered as the microstrip feed line of the antenna, 4.24 mm is used as the size of the patch and 11.528 mm as the size of the ground plane and the substrate, the return loss value is obtained as -3.32 dB at 28 GHz which is a considerably high result.

In addition to that, for 3.93 mm patch size and 9.83 mm ground plane, the return loss is -0.75 dB at 28 GHz. To get a better value the dimension of the patch and the substrate are changed. The best result is obtained when the size of the patch is 4.5 mm, the ground width is 9.5 mm and the ground length is 9.7 mm. In this situation, the return loss of the antenna is obtained as s-16.33 dB. Some of the obtained results are presented in Table 1.

Table 1. Result of Feeding from Bottom of the Microstrip Feed Line

Patch Size (mm)	Ground Width (mm)	Ground Length (mm)	Return Loss (dB) at 28 GHz
4.5	9.5	9.8	-8.08
4.5	9.5	9.9	-11.97
4.55	9.5	9.9	-5.04
4.55	9.5	9.8	-5.8
4.45	9.5	9.8	-10.4

To investigate the effect of the different feeding points, the feed point of the antenna is moved to the center of the microstrip feed line. In this situation, better result is obtained than the feeding from the bottom of the microstrip feed line in return loss. After repetition of the simulation, the return loss is observed as -4.67 dB for 4.24 mm patch size and 11.528 mm ground plane at 28 GHz. In addition, for 3.39 mm patch size and 9.83 mm ground plane, the return loss is found as -2.01 dB.

The best result is obtained when the size of the patch is set to W = 4.45 mm, width and length of the ground plane is 9.5 mm and 9.7 mm respectively. Some of the results according to the new parameters are given in Table 2. The simulated antenna and simulation results are given in Figs. 3, 4, 5, 6, and 7 respectively.

Table 2. Result of Feeding from Middle of the Microstrip Feed Line

Patch Size (mm)	Ground Width (mm)	Ground Length (mm)	Return Loss (dB) at 28 GHz
4.45	9.4	9.8	-17.12
4.45	9.4	9.7	-16.12
4.45	9.4	9.6	-15.6
4.45	11	11	-14.63
4.5	9.4	9.6	-11.93
4.5	9.7	9.6	-11.34

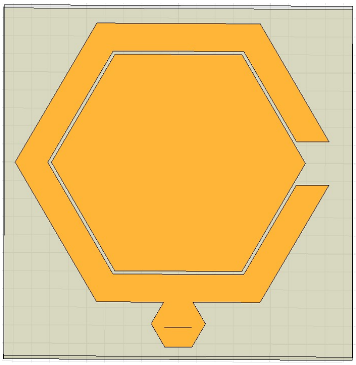


Fig. 3. The Proposed Antenna with Microstrip Feed Line

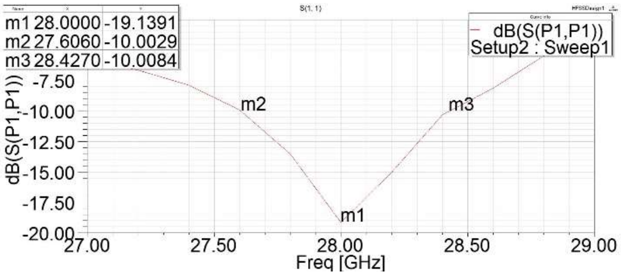


Fig. 4. Return Loss Graph of Microstrip Feed Line

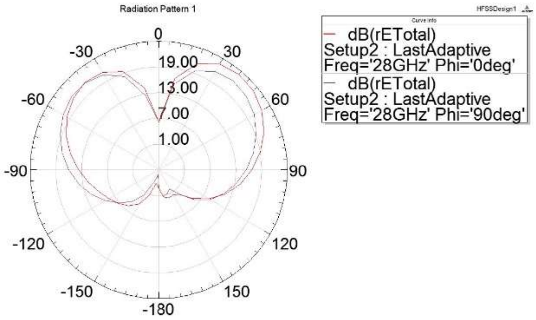


Fig. 5. Radiation Pattern 3D Plot of Microstrip Feed Line when Phi = 0° and 90°

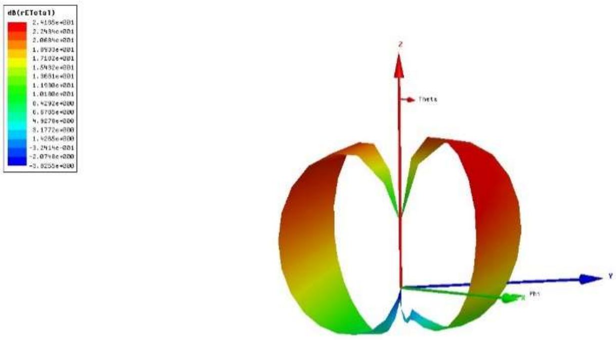


Fig. 6. 3D Plot of the Radiation Pattern of the Antenna

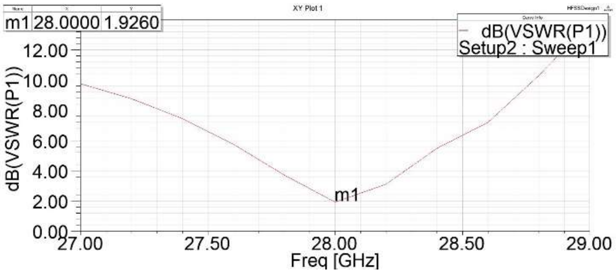


Fig. 7. VSWR Graph of the Antenna

As it is seen from the Fig. 4, the return loss value is -19.14 dB at 28 GHz. The antenna covers the band from 27.6 GHz to 28.4 GHz with overall bandwidth of 800 MHz. At this frequency, the VSWR value is 1.9260 dB which is a low value as expected.

As indicated before in this paper, the position of the feeding point is one of the parameters that affects the input impedance. To obtain a better return loss value, the optimal feed position must be found. Thus, the position of the feeding point of hexagonal patch antenna is changed to the best position. Firstly, the antenna is feed from the bottom of inner hexagonal patch. Secondly, it is feed from the top end point of Ç – shaped patch. Feed points are shown in Fig. 8 and Fig. 9 respectively.

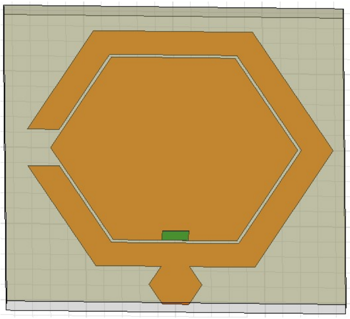


Fig. 8. Feed from the Bottom of the Inner Hexagonal Patch

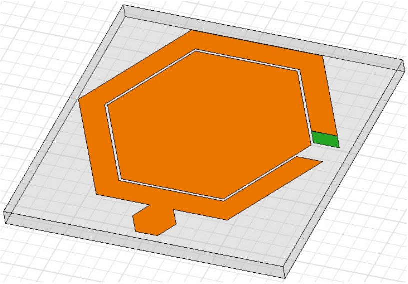


Fig. 9. Feed from the Top End Point of Ç-Shaped Patch

When the return loss graphs of the antennas shown in Fig. 8 and 9 are investigated, it is seen that the return loss of them are very high. For the antenna shown in Fig. 8, the return loss value at 28 GHz is -3.14 dB. For the antenna shown in Fig 9, the return loss value at 28 GHz is -3.05 dB.

2.2. Design and Analyses of Coaxial Feed Method

The coaxial feed method is also used extensively. It is easy to manufacture and match. Also it has low spurious radiation but it has narrow bandwidth but it is not easy to model specially for thick substrates [1]. For the proposed antenna to find the best feeding position for the coaxial feeding method, a trial and error method is used.

Firstly, the antenna is tried to feed from inner hexagon. The center of it is taken as a feeding position. Then x and y values are changed one by one and tried to find the best position. The results for the inner hexagon are given in Table 3 with its x and y values.

Table 3. Results for Coaxial Feed from Inner Hexagon

x (mm)	y (mm)	Return Loss (dB)
0	0	-1.6
-1	0	-2.59
-1.5	0	-3.88
1	0	-2.31
1.5	0	-3.07
0	-1	-2.53
0	-1.5	-3.86
0	1	-2.62
0	1.5	-3.58

Secondly, points on the outer hexagon are investigated and the best result is obtained on the tail of the 'C'. At this position where x = 3.1 mm and y = 0 mm the return loss value is -17.79 dB.

After the best feeding point is found, the size of the inner hexagon is reduced from 2.38 mm to 2.28 mm. As a result of this the resonant frequency decreased to 27 GHz and the return loss is -18.45 dB. To shift the resonant frequency to 28 GHz the length of the substrate is decreased to 7.4 mm. The antenna covers the band from 27.45 GHz to 28.84 GHz with overall bandwidth of 1.39 GHz. The final design of the antenna, the return loss graph, the radiation pattern plots and the VSWR graph are given in Fig. 10, 11, 12, 13 and 14 respectively.

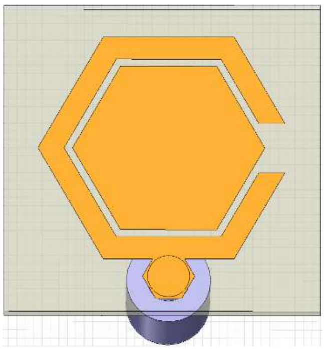


Fig. 10. The Proposed Antenna with Coaxial Feed

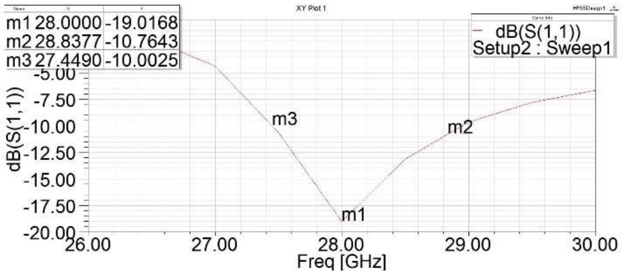


Fig. 11. Return Loss Graph of Coaxial Feed

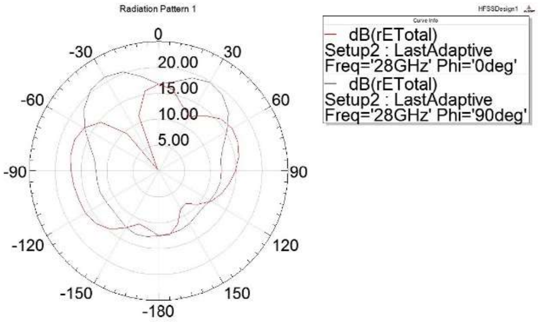


Fig. 12. Radiation Pattern 3D Plot of Coaxial Feed when Phi = 0° and 90°

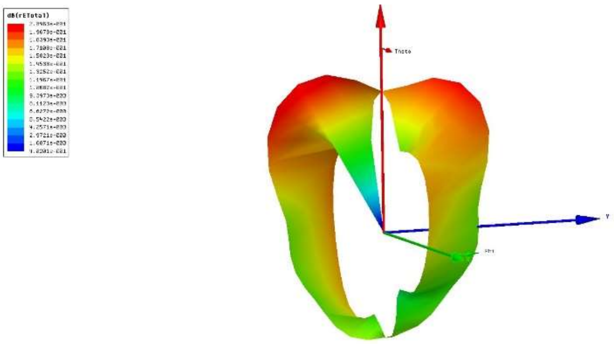


Fig. 13 3D Plot of the Radiation Pattern of the Antenna

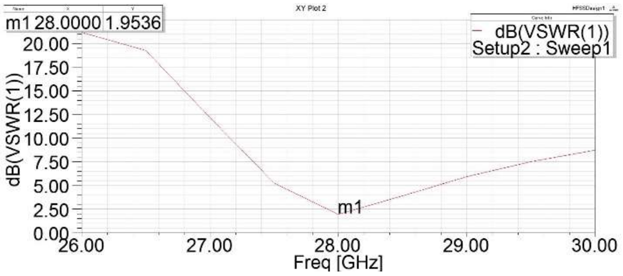


Fig. 14. VSWR Graph of the Antenna

As it is seen from the Fig. 11, the return loss value is -19.02 dB at 28 GHz. The antenna covers the band from 27.45 GHz to 28.84 GHz with overall bandwidth of 1.39 GHz. At this frequency, the VSWR value is 1.9260 dB which is a low value as expected.

Finally, the inner hexagon is removed totally and the resulting return loss is -23.4 dB at 28 GHz. It has a better return loss but its shape is different from the proposed antenna.

3. Conclusion

In this paper, a Ç – shaped patch antenna which can be used for next generation (5G) mobile networks is proposed. The antenna is designed to resonate at 28 GHz and simulated by HFSS 12.0. The dimensions of radiating patch, substrate, ground plane, feeding method and feeding position are investigated in terms of the effects on the antenna performance.

The microstrip feed line has -19.14 dB return loss value while the coaxial feed has -18.45 dB which is lower by 3.54%. When the bandwidth of feeding methods is compared, the coaxial feed method has better values. The coaxial feed line has 1.52 GHz while the microstrip feed line method has 800 MHz which is lower by 47%. In later works, the proposed antenna can be used to design of antenna array for 5G communication systems.

4. Acknowledgements

This study is a part of Orcun Yildiran's M.Sc. Thesis.

5. References

[1] M. E. Shorbagy, R. M. Shubair, M. I. AlHajri, N.K. Mallet, "On the Design of Millimeter-Wave Antennas for 5G", *IEEE*, pp. 1-2, 2016.

[2] S. Ershadi, A. Keshtkar, A. H. Abdelrahman, X. Yu, H. Xin, "Wideband Subarray Design for 5G Antenna Arrays", *URSI Asia-Pacific Radio Science Conference,* Seoul, 2016, pp. 1-2.

[3] H. Zhang, H. Sun, T. Yang, Y. Mahe, T. Razban, "Design of A Wideband and Dual-Polarized CPW-Fed Monopole Antenna for Future 5G Communications", IEEE, pp. 1-2, 2016.

[4] S. E. Jasim, M. A. Jusoh, M. H. Mazwir, S. N. S. Mahmud, "Finding the Best Feeding Point Locaiton of Patch Antenna Using HFSS", *ARPN Journal of Engineering and Applied Sciences*, pp. 1-2, 2016.

[5] S. K. Sidhu, J. S. Sivia, "Comparison of Different Types of Microstrip Patch Antennas", *International Conference on Advancements in Engineering and Technology (ICAET)*, pp. 1-2, 2015.

[6] A. Majumder, "Rectangular Microstrip Patch Antenna Using Coaxial Probe Feeding Technique to Operate in S-Band", *International Journal of Engineering Trends and Technology (IJETT)*, pp. 1-2, 2013.

[7] C. A. Balanis, "Antenna Theory Analysis and Design 2nd Edition", A. John Wiley & Sons Inc., New York, USA, 2005.

[8] J. M. Singh, M. Mishra, P. Sharma, "Design & Optimization of Microstrip Patch Antenna", *International Journal of Emerging Trends & Technology in Computer Sicence (IJETTCS)*, vol. 2, pp. 2, Oct. 2013.