Hexagon-shaped Patch and Array Antenna at 28GHz for Improving the Performance of 5G Technology

Rasim Azeez Kadhim
College of Information Technology, University of Babylon, Babylon, Iraq.
rasimazeez@uobabylon.edu.iq
Corresponding author email: rasimazeez@uobabylon.edu,iq

Received:	30/3/2024	Accepted:	24/4/2024	Published:	9/6/2024

Abstract

Background:

The fifth generation (5G) technology is one of the modernist technologies in the wireless communications field. The design of antenna considers a vital role in 5G technology. In this paper, a proposed antenna is presented and investigated for 5G frequency band (28GHz).

Materials and Methods:

In this paper, a hexagon patch antenna, single and array patch antenna configuration at 28GHz are presented. The proposed antenna design is implemented on substrate (dielectric material) of Rogers RT5880 with size of 8x8 mm^2. Also, 1x2 antenna array sized of 10x16 mm^2 and 1x4 antenna array sized of 13x32mm^2 are constructed based on the proposed hexagon patch element.

Results:

Three configuration are implemented and simulated using the CST software. They are investigated in terms of the performance metrics represented by the Voltage Standing Wave Ratio (VSWR), gain, bandwidth, angular width, and total efficiency. The first configuration of a single hexagon antenna provides a gain of 7 dBi with excellent impedance matching (VSWR=1.259), an efficiency of 81%, an angular width of 165.6 degrees, and a bandwidth of 0.637 GHz. The second configuration of 1x2 hexagon antenna array achieves a gain of 8.9 dBi with excellent impedance matching (VSWR=1.9), an efficiency of 80%, an angular width of 48.2 degrees, and a bandwidth of 0.554 GHz. The third configuration of 1x4 hexagon antenna array demonstrates a gain of 12 dBi with excellent impedance matching (VSWR=1.45), an efficiency of 82%, an angular width of 18.8 degrees, and a bandwidth of 0.45 GHz. .

Conclusion:

The results highlight the impact of array geometry on gain, impedance matching, efficiency, angular coverage, and bandwidth. By elucidating these parameters, this research contributes to the advancement of millimeter-wave communication technologies, facilitating the design of high-performance antennas for various wireless communication applications in the 28 GHz frequency band.

Keywords: fifth-generation (5G), millimeter-wave, array antenna, hexagon antenna, 28GHz band.

Introduction

Over the recent years, the demand of human for high quality of services represented by high rate of transferring data through the communication channel, encouraged the industrials of wireless mobile communication to develop new communication technologies. This developing of technologies represented by the generations of the mobile communications that starting with the first generation (1G), second generation (2G), third generation (3G), fourth generation (4G) and fifth generation (5G). A considerable interest with 5G was received by various industrial fields due to it's capability to provide high throughput, fast connection, low latency, ultra-reliability, and more capacity. The 5G can be implemented and operated at two frequency bands, the first band is the lower band that is beyond 6GHz which is used for long distances and low data rate, and the second band is above 6GHz up-to 100GHz specially the unlicensed band of 24.25-29.5GHz. The millimeter band has been considered a good candidate for 5G communication because it has a large bandwidth in which it provides higher data rate services [1-3]. Many researches have been done in this area where antennas designed for single and multiband [4-8].

The 5G technology considers number of antennas as an important factor represented by the multiple input multiple output (MIMO) system to achieve the requirements of the new generation. The properties of patch antenna represented by the low cost, robust design, lightweight and the moderate performances, made him the preferable choice in different areas such as military systems, mobile satellite communications, wireless local area networks, and for the 5G new Radio Communication Systems. Also, the phased array antenna is a promising technique for exploiting the millimeter frequency band [9],[10].

In [11], three models of antenna was proposed for operation in the band of 28GHz. A rectangular shape was used with multiple slots was used to design these three models fabricated on FR4 dielectric substrate. These antennas gave a good performance but low efficiency in the first model which increased in the third model. In [12], the authors presented a rectangular patch antenna to operate at 28 GHz based on a substrate material of Rogers RT Duroid 5880 with thickness of 1.57mm. This antenna achieved a large bandwidth, but low gain value. In [13], a T-shaped patches of 1x4 elements was designed on Rogers RT Duroid 5880 material substrate with the defect ground structure (DGS) approach to achieve a bandwidth of 12.4 GHz, covering from

25.1-35.1 GHz. This approach does not suitable for 5G requirement because the coplanar-waveguide feeding limits the array configuration based on T-shaped antenna.

In this work, we present a hexagon patch antenna and an antenna array with different arrangements that consists of many patch antennas with microstrip lines feeding operating at 28GHz for 5G application. To fit the requirements, the parameters of the patch antenna structure are calculated based on design antenna equations and modified .

The remainder of this paper is organized as follows: Section II contains the design of the single patch and array antenna. Also, the parameters of the substrate are presented in this section. The third section discusses the simulation results of the designed single element and array antenna. Finally, we conclude the research in the last section.

System Model

Design of Single Patch Antenna

The structure of patch antenna consists of a conducting patch and a ground plane in addition to substrate between them that can be a dielectric such as Rogers RT5880. The design process of a rectangular patch antenna starts with the knowledge of the key factors for instance resonance frequency, dielectric constant and thickness of the dielectric material that is used as a substrate. Then, apply the design equations to compute the antenna parameters represented by the antenna dimensions as follows [3].

$$W = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \quad (1)$$

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 0.824h\left(\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)}\right) \quad (2)$$

Where

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{W}\right)}}\right] \quad (3)$$

The width and length of the rectangular patch antenna are calculated based on the above equations where the relative permittivity was 2.2 and the height was 0.2mm of the substrate dielectric (Rogers RT5880). The calculated values of width and length of the rectangular patch are W=4.23mm and L=3.5mm for operating frequency of 28GHz. The configuration of the hexagon patch antenna depends on the size of the rectangular antenna with some modifications on the dimensions as illustrated in Figure 1.

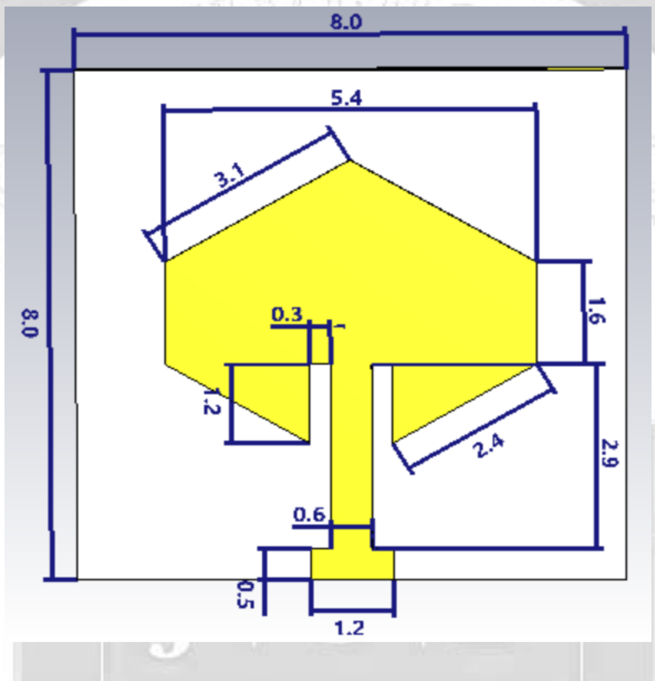

Figure 1: The designed hexagon patch antenna

Design of 1x2 hexagon Patch Antenna Array

The structure a 1*2 antenna array was designed based on the designed hexagonal antenna, where two antennas were placed side by side over a substrate of Rogers RT5880 dielectric material with an area of 10*16 mm. The dimensions of the antenna feed were determined to achieve matching at a frequency of 28 GHz. The configuration of the 1*2 hexagon patch antenna array is shown in Figure 2.

ARTICLE
JOURNAL`S UNIVERSITY OF BABYLON FOR ENGINEERING SCIENCES (JUBES)
مـــجلـة جـــامعة بـــــابـل للعلــــــوم الهندسية
Vol. 32, No. 3. \ 2024 ISSN: 2616 - 9916

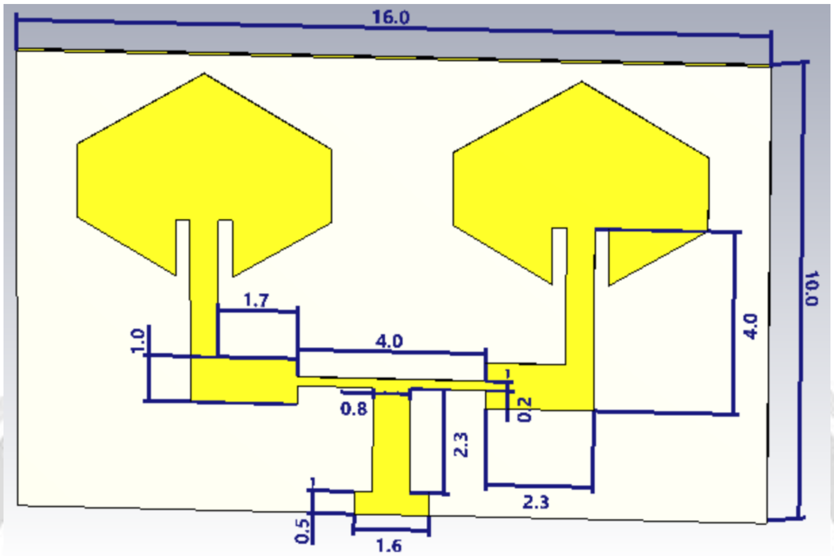

Figure 2: The designed 1x2 hexagon patch antenna array

Design of 1x4 Patch Antenna Array

The structure a 1*4 antenna array was designed based on the designed hexagonal antenna, where four antennas were placed side by side over a substrate of Rogers RT5880 dielectric material with an area of 13*32 mm. The dimensions of the antenna feed were determined to achieve matching at a frequency of 28 GHz. The configuration of the 1*4 hexagon patch antenna array is shown in Figure 3.

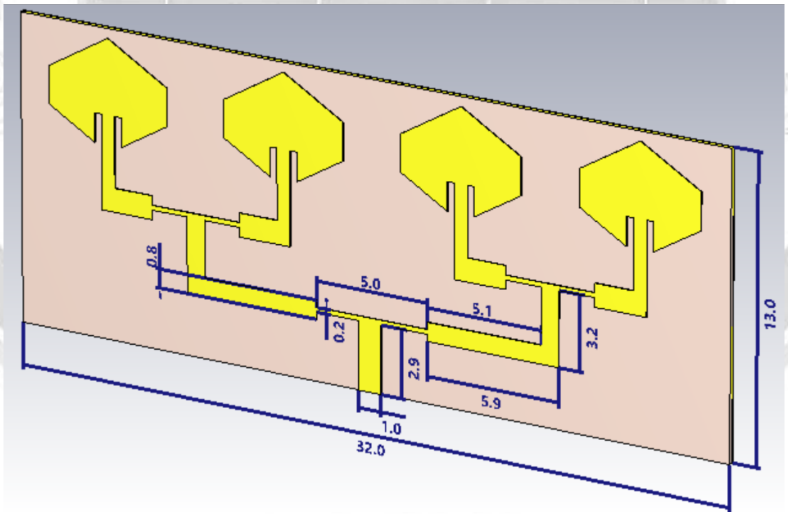

Figure 3: The designed 1x4 hexagon patch antenna array

Simulation Results

The design of patch array antenna at 28 GHz and obtained results have been discussed in this section. The hexagon patch antenna and hexagon array antenna are designed and simulated using CST software to exhibits its simulation results. **Figure** 4 shows the reflection coefficient or S11 of the single patch antenna. It is clear that the designed antenna at 28 GHz with bandwidth of 0.637GHz satisfied the requirement level of -10dB in which it is less than -10 dB. Also, the VSWR of this antenna is less than 2 at a frequency of 28GHz as shown in Figure 5. Moreover, **Figure** 6 and **Figure** 7 illustrates the electric far-field pattern in 3-D and 1-D where the gain of this antenna about 7.02 dBi. Also, the angular width of the beam pattern is 165.6 deg.

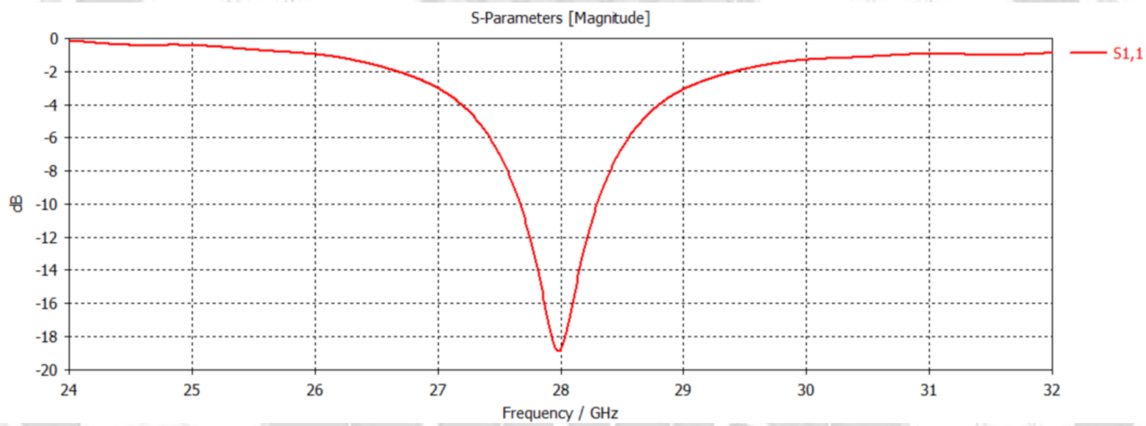

Figure 4: The reflection coefficient of the hexagon patch antenna

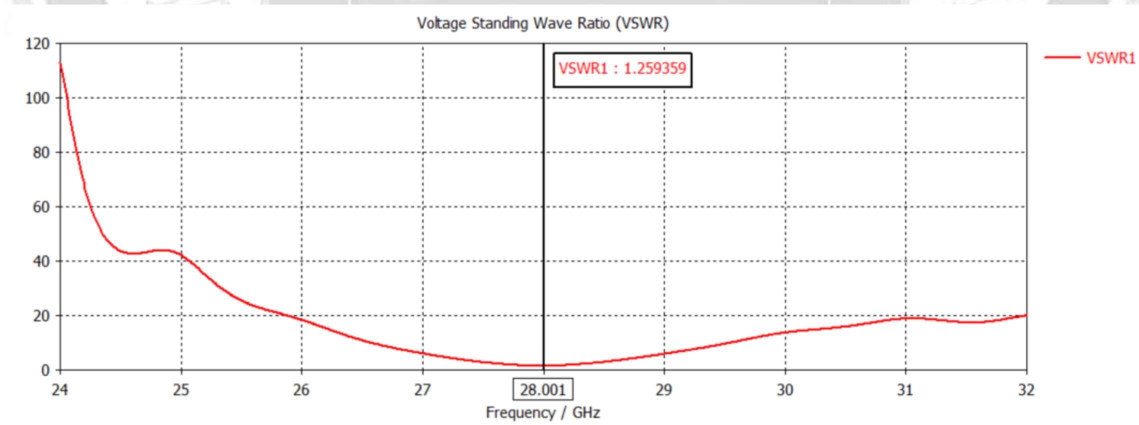

Figure 5: The VSWR of the hexagon patch antenna

ARTICLE
JOURNAL`S UNIVERSITY OF BABYLON FOR ENGINEERING SCIENCES (JUBES)
مـــجلـة جـــامعة بـــــابـل للعلــــوم الهندسية
Vol. 32, No. 3. \ 2024 ISSN: 2616 - 9916

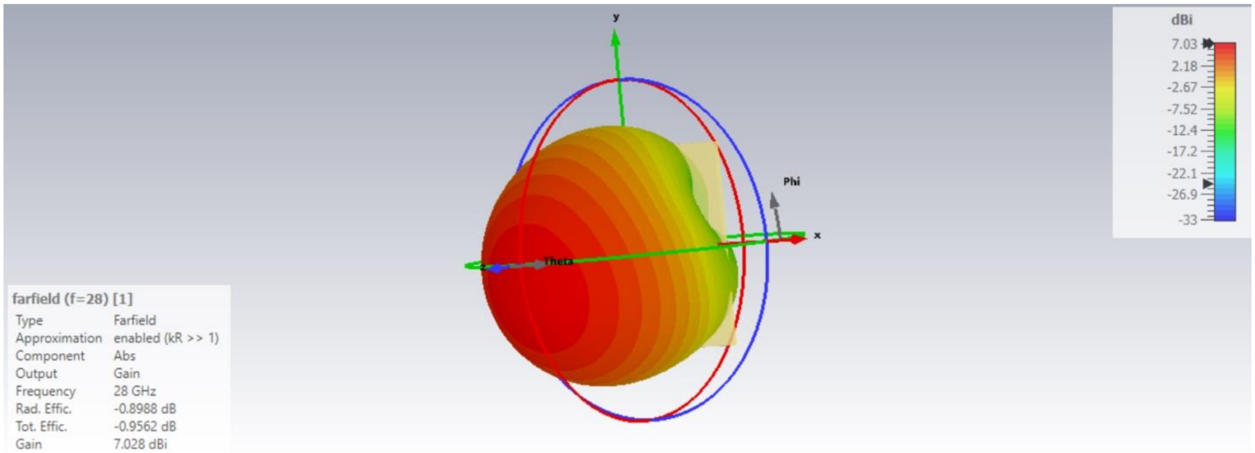

Figure 6: The 3-D farfield of the hexagon patch antenna

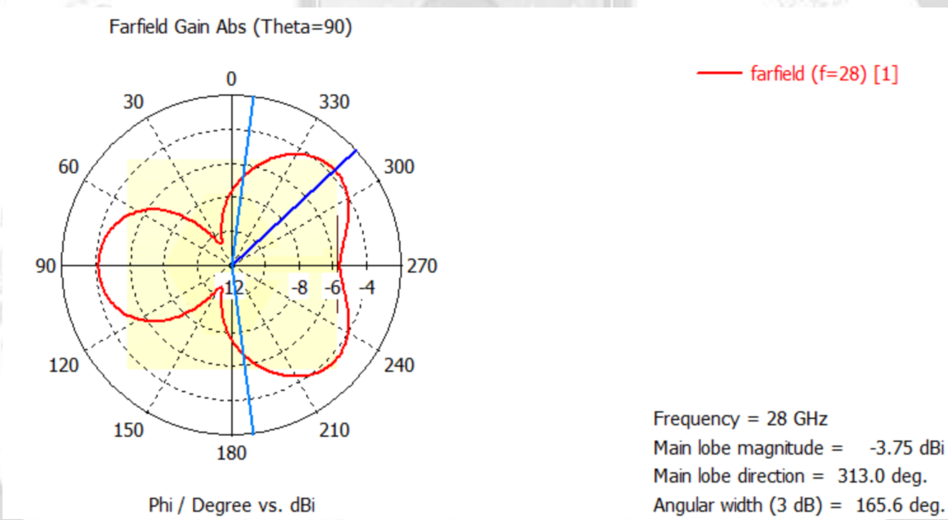

Figure 7: 1-D farfield of the hexagon patch antenna

Figure 8 shows the s-parameter of the 1x2 hexagon patch antenna array where the antenna achieved -12dBi and a bandwidth of 0.554GHz . Also, this structure of patch antenna array provides VSWR =1.9 at 28GHz which is acceptable less than 2 as shown in Figure 9. Figure 10 and Figure 11 present the far-field pattern in 3-D and 1-D for the case of using 1x2 patch array antenna. It is clear that the gain increased to 8.9dBi. Also, the angular width of the beam pattern decreased to 48.2 deg.

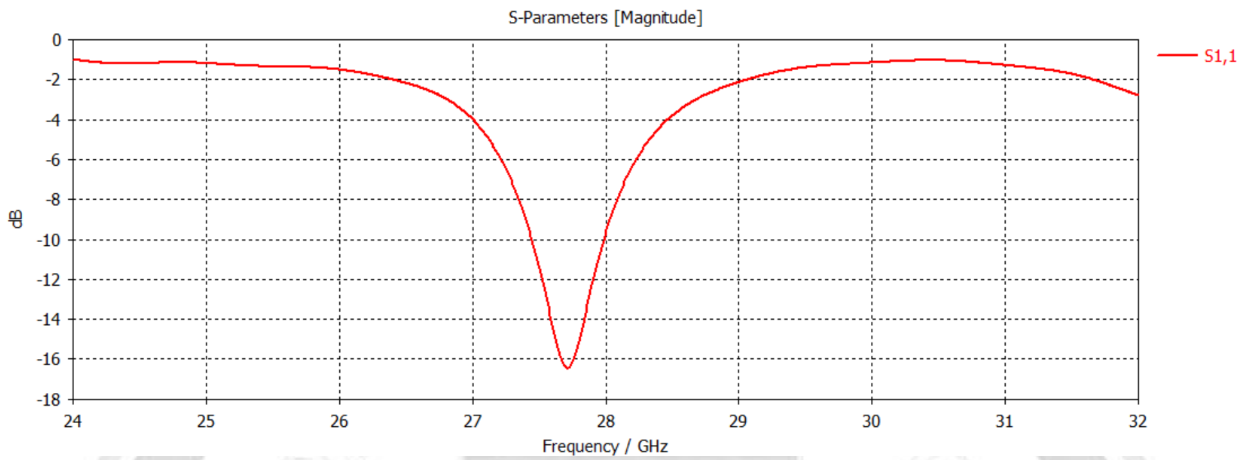

Figure 8: The reflection coefficient of the 1x2 hexagon patch antenna array

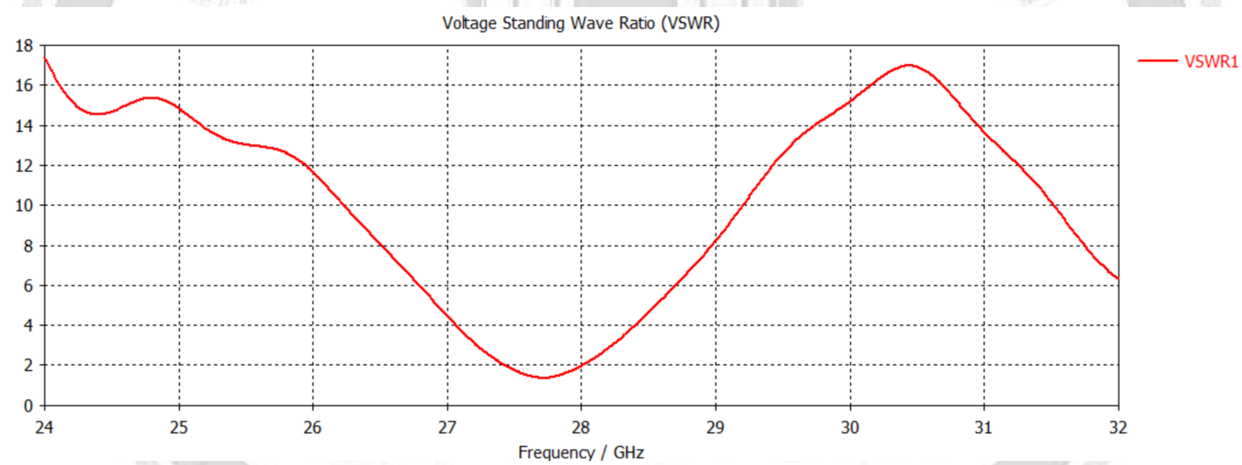

Figure 9: The VSWR of the 1x2 hexagon patch antenna array

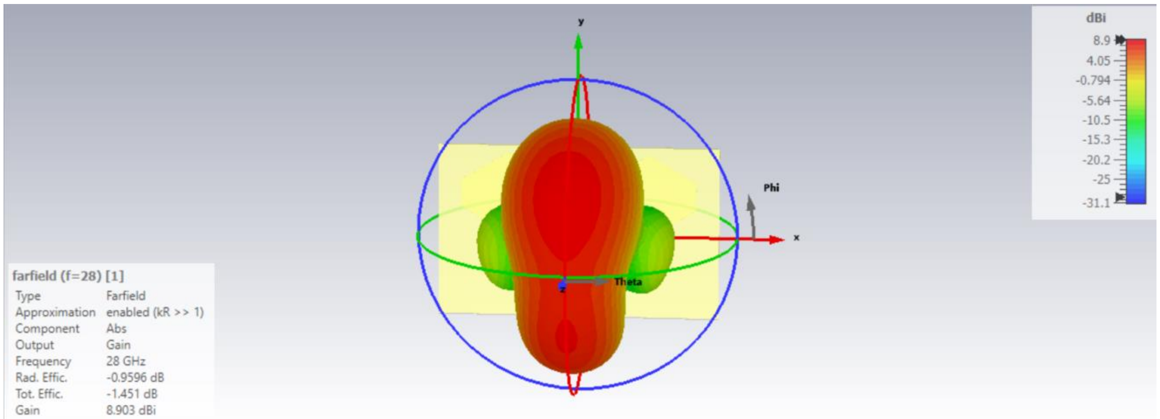

Figure 10: 2-D farfield of the 1x2 hexagon patch antenna array

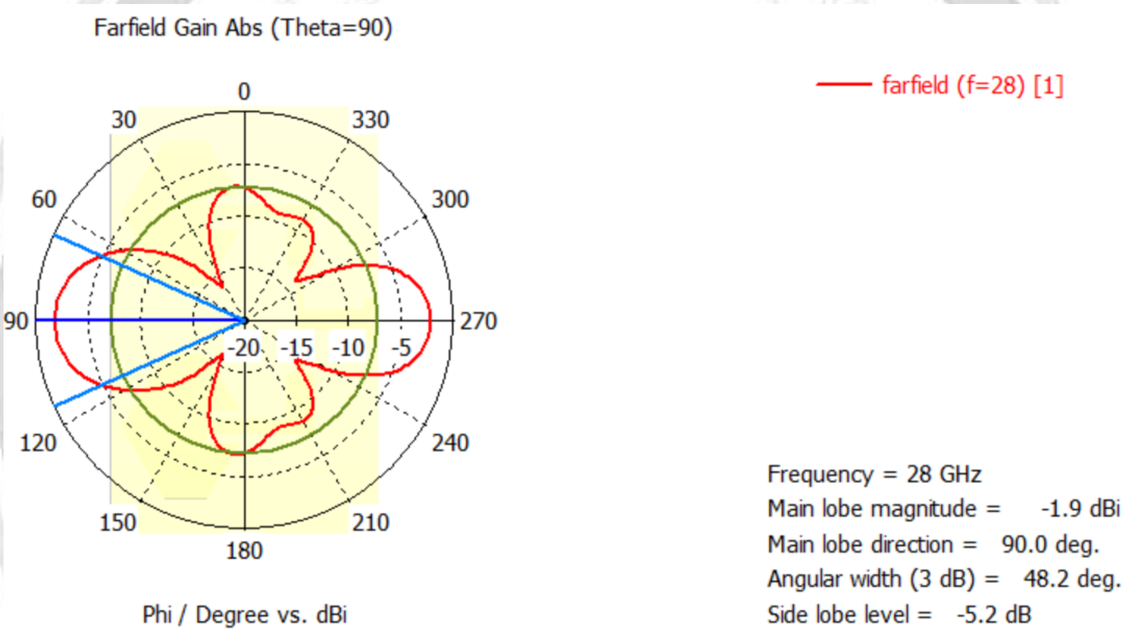

Figure 11: 1-D farfield of the 1x2 hexagon patch antenna array

Figure 12 shows the s-parameter of the 1x4 hexagon patch antenna array where the antenna achieved -15dB and a bandwidth of 0.45GHz. Also, this structure of patch antenna array provides VSWR =1.45 at 28GHz which is acceptable less than 2 as shown in Figure 13. Figure 14 and Figure 15 present the far-field pattern in 3-D and 1-D for the case of using 1x4 patch array antenna. It is clear that the gain increased to 12dBi. Also, the angular width of the beam pattern is 18.8 deg.

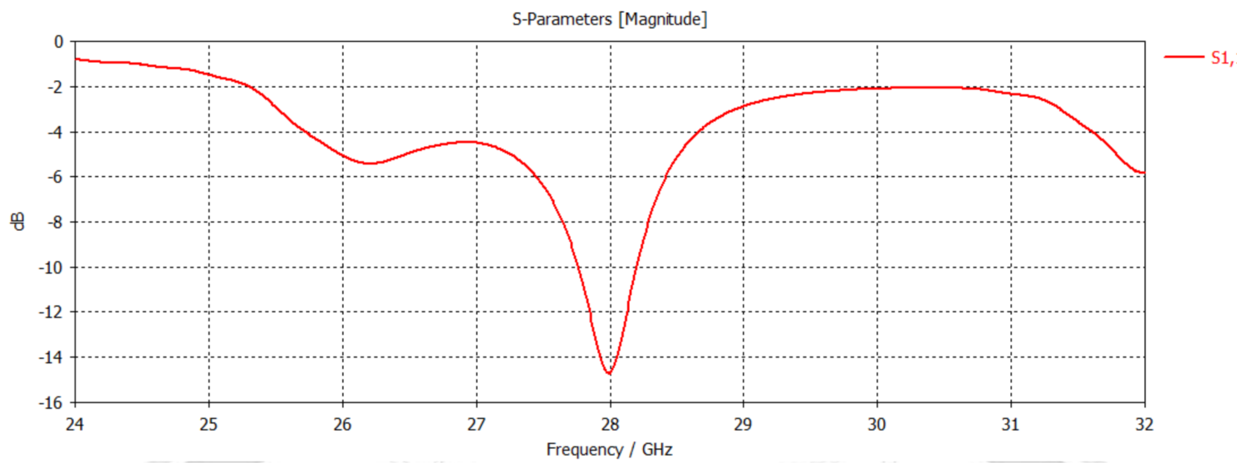

Figure 12: The reflection coefficient of the designed 1x4 hexagon patch antenna array

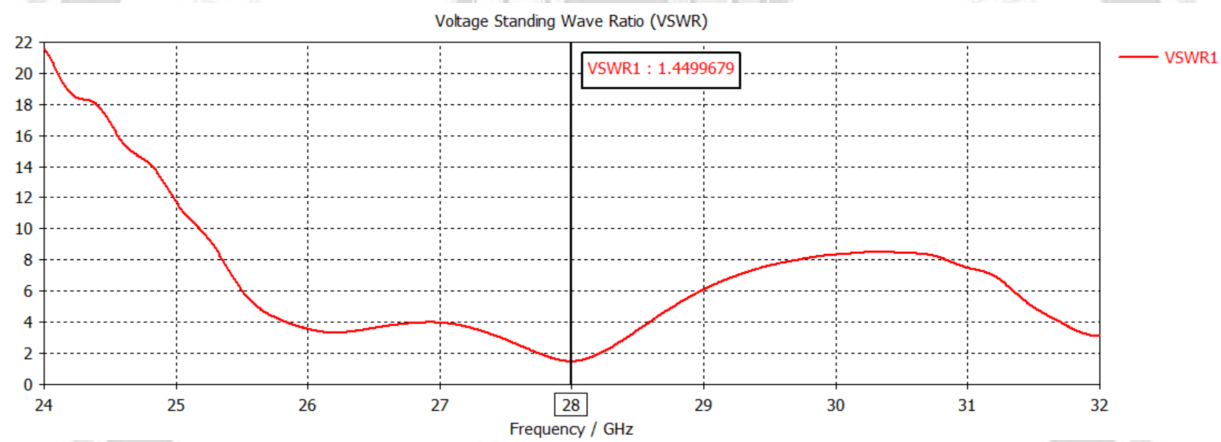

Figure 13: The VSWR of the 1x4 hexagon patch antenna array

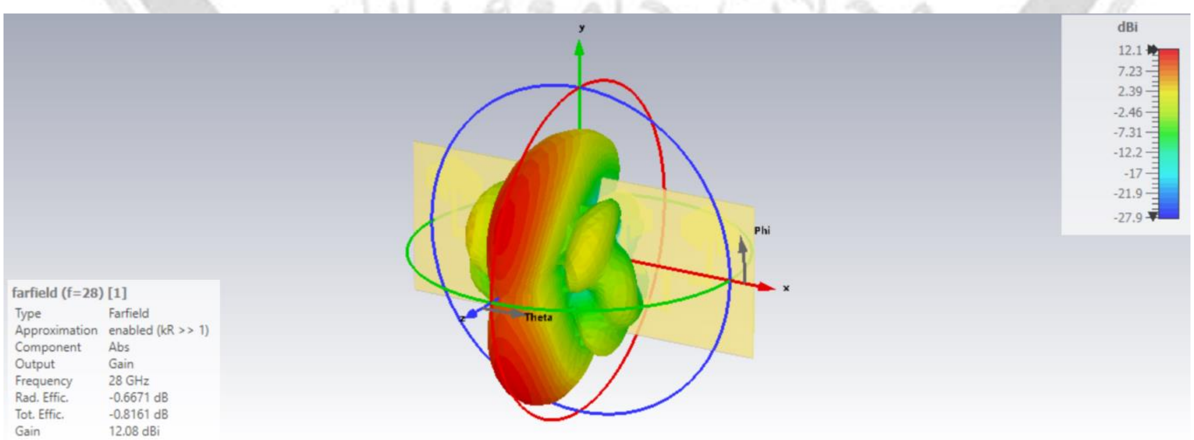

Figure 14: 3-D farfield of the 1x4 hexagon patch antenna array

ARTICLE
JOURNAL`S UNIVERSITY OF BABYLON FOR ENGINEERING SCIENCES (JUBES)
مـــجلـة جـــامعة بـــــابـل للعلـــــوم الهندسية
Vol. 32, No. 3. \ 2024 ISSN: 2616 - 9916

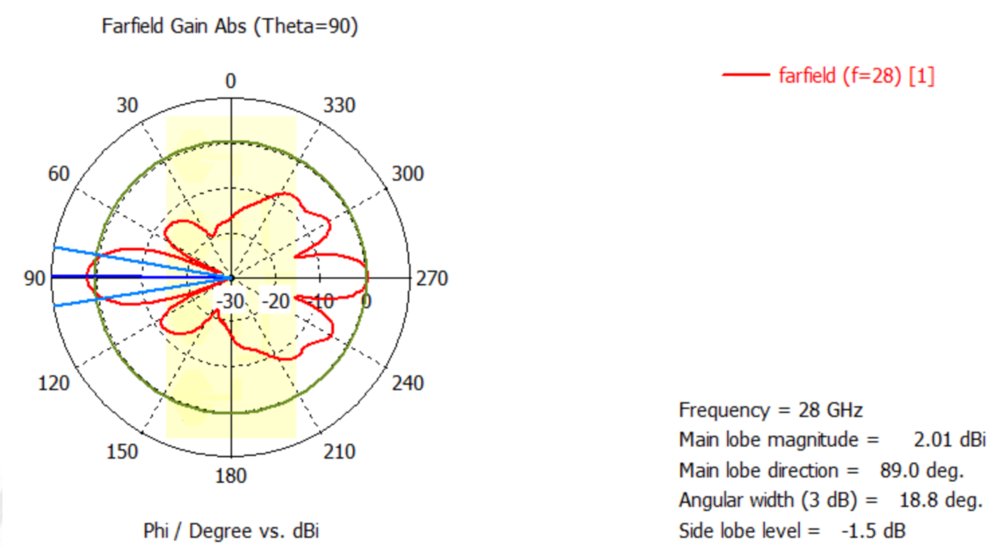

Figure 15: 1-D farfield of the 1x4 hexagon patch antenna array

Discusion

The summery of the results for all cases is presented in Table 1. It can be discussed as follows according to the performance metrics represented by the gain, VSWR, total efficiency, angular width and bandwidth.

Gain

An antenna's gain indicates its capacity to focus or steer radiation in a specific direction. In this instance, the 1x4 hexagon patch antenna array in the third configuration outperformed the others in terms of directional performance, achieving the maximum gain of 12 dBi. When compared to the single hexagon patch antenna in the first configuration, the 1x2 array in configuration two likewise displayed a notable gain enhancement, highlighting the advantages of array arrangements for improving antenna performance.

VSWR

The impedance matching between the transmission line and the antenna is measured by VSWR. Better impedance matching and less signal reflections are indicated by a lower VSWR value. The single hexagon patch antenna showed the lowest VSWR of 1.259 in this study, which provides good impedance matching. Moreover, the second and third configurations of hexagon antenna array displayed marginally elevated VSWR values, that is a less optimal impedance match.

Antenna Efficiency

The radiation efficiency is a measure of the ability of the antenna to transform the input power into radiated power. High values of efficiency indicates better performance and fewer power loss. In this work, the third configuration of 1x4 patch antenna array had the highest efficiency of 85%, outperforming the other configurations.

Angular Width

Angular width is the range of angular values over which the antenna's performance parameters—such as radiation pattern and gain—remain within allowable bounds. Greater omnidirectional performance and wider coverage are indicated by a bigger angular breadth. With an angular width of 165 degrees, the single patch antenna has the widest coverage compared with the other configurations. The 1x4 array patch antenna displayed the narrowest angular width of 18.8 degrees, suggesting greater directional performance than the others, although the 1x2 array patch antenna showed a narrower angular width of 48.2 degrees.

Bandwidth

The range of frequencies that an antenna can maintain certain performance standards throughout is referred to as its bandwidth. The comparison showed that the 1x4 array in the third configuration had the narrowest bandwidth of 0.45 GHz, the 1x2 array in the second configuration had a bandwidth of 0.554 GHz, and the single hexagon patch antenna had the widest bandwidth of 0.637 GHz. In the second and third configurations, the way the antennas are arranged may naturally make the signal range narrower than the single patch antenna. Arrays can make the elements interact with each other, which can change how well electricity can flow and limit the frequencies that can be used. Also, the size and shape of the antenna parts are important for deciding how wide the antenna can receive and send signals.

ARTICLE
JOURNAL`S UNIVERSITY OF BABYLON FOR ENGINEERING SCIENCES (JUBES)
مـــجلــة جـــــامعة بـــــــابـل للعلـــــــوم الهندسية
Vol. 32, No. 3. \ 2024 ISSN: 2616 - 9916

Moreover, Table 1 shows the comparison of the proposed antennas with the existing results. Here the size of antenna, gain, VSWR, efficiency, angular width, and bandwidth are compared. It is clear that the proposed single patch antenna achieved a gain higher than the previous antenna with comparable size of antenna and efficiency but the bandwidth is much small. Also, the array antenna configuration increases the values of gain and the efficiency with the narrowest angular beam width.

Table-1: The Summery and Comparison of the Results

Antenna Configuration	Size of Antenna (mm*mm)	Gain of Antenna (dBi)	VSWR	Efficiency of Antenna (%)	Angular width (deg)	Bandwidth of Antenna (GHz)
Ref.[6], antenna III	7x7	6.59	1.08	82		2.62
Ref.[7]	6.2x8.4	5.06	1.16	80.18	115.04	5.5
Single Patch Antenna	8x8	7.05	1.259	80	165.6	0.637
1x2 Array Antenna	10x16	8.9	1.9	80	48.2	0.554
1x4 Array Antenna	13x32	12	1.45	85	18.8	0.45

Conclusion

The proposed hexagon patch antenna used as a single and multiple elements of antenna array that operating at 28 GHz, that suggested band for 5G applications were investigated in this paper. The antenna was designed and simulated for all cases under study using CST. The performance of the designed antenna was evaluated in terms of efficiency, gain, angular width and return loss. By analyzing the results we inferred that the gain and directivity increases if the array elements increased. The performance characteristics for the array of hexagon topology patch antennas at 28 GHz demonstrate the trade-offs between bandwidth, angular coverage, efficiency, gain, and impedance matching. This research advances millimeter-wave communication technology by clarifying these trade-offs and facilitating the creation of customized antenna systems that can accommodate the wide range of needs of contemporary wireless communication applications in the 28 GHz frequency range.

References

[1] J. G. Andrews et al., “What will 5G be?”, IEEE J. Sel. Areas Commun., vol. 2, no. 6, pp. 1065–1082, Jun. 2014.

[2] T. S. Rappaport et al., “Millimeter wave mobile communications for 5G cellular: It will work!”, IEEE Access, vol. 1, pp. 335–349, May 2013.

[3] A. Balanis, “Antenna Theory Analysis and Design”. New Jersey, 2005.

[4] H. Ullah , FA. A. Tahir. “broadband wire hexagon antenna array for future 5G communications in 28 GHz band”. Microw Opt Technol Lett. Vol. 61: pp. 696–701. 2019.

[5] L. Getnet Ayalew, and F. Melak Asmare. "Design and optimization of pi-slotted dual-band rectangular microstrip patch antenna using surface response methodology for 5G applications". *Heliyon*, Vol. 8, no. 12. Dec. 2022.

[6] S. Yaseen Younus, & M. Taih Gatte. “Design of dual bands microstrip patch antenna for 5G applications”. In *AIP Conference Proceedings*. Vol. 2804, No. 1. AIP Publishing. September, 2023.

[7] R. Azeez Kadhim, Y. Naser Jurn, and M. Taih Gatte. "Dual band antenna in licensed and unlicensed frequency bands based on superformula for 5G applications". *Bulletin of Electrical Engineering and Informatics, Vol.* 12, no. 5 : pp. 2846-2851. Oct. 2023.

[8] N. Elhouda Nasri , M. EL GHZAOUI , M. Fattah. “ A quad port MIMO antenna with improved bandwidth and high gain for 38 GHz 5G applications”. *Franklin Open.* 2024

[9] CX. Wang et al. “Cellular Architecture and Key Technologies for 5G Wireless Communication Networks”. IEEE Communications Magazine. Vol. 52, no. 2, pp. 122-130, 2014.

[10] A. Osseiran et al. “Scenarios for 5G Mobile and Wireless Communications: The Vision of the METIS project”. IEEE Communications Magazine.vol. 52, no. 2, pp. 26-35, 2014.

[11] P. Merlin Teresa, and G. Umamaheswari. "Compact slotted microstrip antenna for 5G applications operating at 28 GHz." *IETE Journal of Research, vol.* 68, no. 5, Sep. 2022, pp. 3778-3785.

[12] P. Rafal, M. Bugaj, and L. Nowosielski. "Broadband microstrip antenna for 5G wireless systems operating at 28 GHz." *Electronics, vol.* 10, no. 1, Dec. 2020.

[13] SF. Jilani, A. Alomainy. “Millimetre-wave T-shaped antenna with defected ground structures for 5G wireless networks”. In 2016 Loughborough Antennas and Propagation Conference, LAPC 2016. 2017, Lapc 2016, pp. 8–13.

Vol. 32, No. 3. \ 2024 ISSN: 2616 - 9916

هوائي رقعة سداسي الشكل ومصفوفة هوائيات بتردد 28 كيكاهيرتز لتحسين اداء تكنولوجيا 5G

راسم عزيز كاظم
كلية تكنولوجيا المعلومات، جامعة بابل، rasimazeez@uobabylon.edu.iq ، بابل، العراق

الخلاصة

مقدمة:

تقنية الجيل الخامس (G5) إحدى التقنيات الحديثة في مجال الاتصالات اللاسلكية. يعتبر تصميم الهوائي دورًا حيويًا في تقنية G5. في هذا البحث، تم عرض هوائي مقترح ودراسة امكانية ملائمته لتطبيقات G5 (28GHz).

طريقة العمل:

في هذا البحث، يتم عرض هوائي رقعة سداسي وتكوين مصفوفة هوائيات تعمل عند 28 جيجا هرتز. يتم تنفيذ هوائي رقعة سداسي على طبقة من مادة الروجرز RT5880 الذي يستخدم كعازل وطبقة اساس لطبقة الموصل بحجم 8 × 8 مم ^{2}. بالاضافة الى ذلك، تم إنشاء مصفوفة هوائي 1x2 بحجم 16×10 مم^2 ومصفوفة هوائي 1x4 بحجم 32×13 مم^2 استنادًا إلى عنصر الرقعة السداسي.

النتائج:

تم تنفيذ ومحاكاة ثلاثة تكوينات باستخدام برنامج CST. يتم فحصها من حيث مقاييس الأداء التي تمثلها نسبة الموجة الدائمة للجهد (VSWR)، والكسب، وعرض النطاق الترددي، والعرض الزاوي، والكفاءة الإجمالية. يوفر التكوين الأول لهوائي سداسي واحد كسبًا قدره 7 ديسيبل مع مطابقة مقاومة ممتازة (VSWR = 1.259)، وكفاءة قدرها 81%، وعرض زاوي قدره 165.6 درجة، وعرض نطاق قدره 0.637 جيجا هرتز. التكوين الثاني لصفيف الهوائي السداسي 1x2 يحقق ربحًا قدره 8.9 ديسيبل مع مطابقة مقاومة ممتازة (VSWR=1.9)، وكفاءة تبلغ 80%، وعرض زاوي قدره 48.2 درجة، وعرض نطاق يبلغ 0.554 جيجا هرتز. يوضح التكوين الثالث لصفيف الهوائي السداسي 1x4 كسبًا قدره 12 ديسيبل مع مطابقة مقاومة ممتازة (VSWR = 1.45)، وكفاءة قدرها 85%، وعرض زاوي قدره 18.8 درجة، وعرض نطاق قدره 0.45 جيجا هرتز.

الاستنتاج:

تسلط النتائج الضوء على تأثير استخدام مصفوفة هوائيات على الكسب ومطابقة المعاوقة والكفاءة والتغطية الزاوية وعرض النطاق الترددي. ومن خلال توضيح هذه المعلمات، يساهم هذا البحث في تحسين تقنيات اتصالات الموجات المليمترية، مما يسهل تصميم هوائيات عالية الأداء لمختلف تطبيقات الاتصالات اللاسلكية في نطاق التردد 28 جيجا هرتز.

الكلمات الدالة: الجيل الخامس (G5)، الموجة المليمترية، هوائي المصفوفة، هوائي سداسي, نطاق 28 كيكاهيرتز.