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Design of Microstrip Antenna Array for Autonomous Vehicles

Noor Qasim Ali[1], Hassan F.Khazaal Al-khazaali[1]

Affiliations
[1]Department of Electrical Engineering, Wasit University, Wasit, Iraq.

Correspondence
Noor Qasim Ali
Std2022203.N.Qasim@uowasit.edu.iq

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Abstract

The utilization of Autonomous vehicles has been rapidly increasing in both civilian and military applications. This is primarily due to their exceptional communication capabilities with ground clients, as well as their inherent properties such as adaptability, mobility, and flexibility. To effectively monitor and control the deployment of Autonomous vehicles, a 5G wireless network can be utilized alongside other devices as user equipment (UE). Through the utilization of a highly directive microstrip patch antenna (MPA) functioning within a dedicated frequency band, the Autonomous vehicle is able to establish effective long-range communication, overcoming signal degradation and minimizing interference from other channels within a confined area. The adoption of MPA is especially advised for Unmanned Aerial Vehicles (UAVs) due to its characteristics such as being lightweight, cost-efficient, small in size, and having a flat structure. This study details the development and simulation of a highly directive single-band 1x2 and 1x4 antenna array designed to operate at a 5.8 GHz frequency specifically tailored for Autonomous vehicle use. To enhance directivity and ensure structural robustness, the Roger RT5880 material has been utilized as a substrate, known for its lower dielectric constant.. The results demonstrate a high gain of 9.16 dBi and 11.4 dBi for the 1x2 and 1x4 antenna arrays respectively, while maintaining a compact size. The simulated 1x4 antenna array was fabricated using the Roger RT5880 material, and this array was tested in the microwave communication's laboratory at College of Engineering, Al-Nahrain University. The antenna presents good results by means of return losses (-26.672 dB) which equivalent to VSWR of 1.098.

Keywords: microstrip patch antenna (MPA) ; return losses; VSWR; Gain; Directivity.

الخلاصة:

يتزايد استخدام المركبات ذاتية القيادة بسرعة في التطبيقات المدنية والعسكرية. ويرجع ذلك في المقام الأول إلى قدراتها الاستثنائية على التواصل مع العملاء، فضلاً عن خصائصها المتأصلة مثل القدرة على التكيف والتنقل والمرونة. لمراقبة نشر المركبات ذاتية القيادة والتحكم فيها بشكل فعال، يمكن استخدام شبكة G5 اللاسلكية جنبًا إلى جنب مع الأجهزة الأخرى كمعدات مستخدم (UE) من خلال استخدام هوائي الرقعة الشرائحي عالي التوجيه (Microstrip Patch Antenna (MPA)) يعمل على نطاق محدد خصيصًا، يمكن للمركبة المستقلة إنشاء اتصالات بعيدة المدى والتغلب على توهين الاشارة وتقليل تداخل القناة المشتركة داخل منطقة محدودة. يوصى باستخدام MPA بشكل خاص للطائرات المسيّرة (UAVs) نظرًا لوزنها الخفيف وفعاليتها من حيث التكلفة وحجمها الصغير وشكلها المسطح. في هذه الدراسة، قمنا بتصميم ومحاكاة مصفوفة هوائيات أحادية النطاق 1×2 و1×4 عالية التوجيه تعمل بتردد GHz5.8، خصيصًا لتطبيقات المركبات الذاتية الحركة. لتحقيق اتجاهية أعلى واستقرار ميكانيكي جيد، استخدمنا مادة (Roger RT5880) كطبقة أساس (ركيزة)، معروفة بثابت العزل الكهربائي المنخفض. تم استخدام تقنية التغذية الداخلية لتقليل مقاومة دخل الهوائي، وبالتالي تعزيز كفاءة الهوائي. وتظهر النتائج كسب (ربح) عالٍ يبلغ dBi 9.16 و dBi 11.4 لمصفوفتي الهوائي ذات العنصرين وذات الأربعة عناصر على التوالي، مع الحفاظ على الحجم الصغير. بعد نجاح عملية المحاكاة تم تصنيع هوائي المصفوفة (x14) على ركيزة نوع (Roger RT5880) وتم اجراء الفحص العملي في مختبر الاتصالات اللاسلكية في كلية الهندسة في جامعة النهرين وكانت النتائج المستحصلة جيدة، إذ بلغت قيمة الخسائر الراجعة (-dB 26.672).

1. INTRODUCTION

Reliable and high-performance communication systems are now essential for facilitating seamless connectivity and data exchange due to the rapid advancements in autonomous vehicle technology. The antenna, which is essential to both transmitting and receiving signals, is one of the basic parts of these communication systems [1]. Within this framework, considerable interest has been shown in the design of a microstrip antenna array specifically intended for autonomous cars running at 5.8 GHz frequency band [2-4].

Several wireless communication applications, such as vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication in autonomous driving scenarios, make extensive use of the 5.8 GHz frequency band [5]. Microstrip antenna arrays are an appealing option for integration into autonomous vehicles because they can be used to achieve desired features like high gain, beamforming capabilities, and compact form factor [6-9].

The design elements of a microstrip antenna array especially suited for autonomous cars running at 5.8 GHz are the main topic of this article. Careful considerations such as gain requirements, beam width, polarization, impedance matching, and overall system integration are involved in the design of the antenna array [10]. The goal is to develop an antenna array that satisfies the strict size and performance requirements of autonomous vehicles while offering dependable and strong wireless communication capabilities [11-13].

The design process encompasses determining the optimal antenna array configuration, selecting the appropriate number of elements, calculating the element spacing, designing individual microstrip antenna elements, designing the feeding network, and conducting simulations to optimize the array's performance [14]. Furthermore, fabrication techniques and testing methodologies are discussed to ensure the practical realization and validation of the designed antenna array [15-19].

The design of a microstrip antenna array for autonomous vehicles operating at 5.8 GHz is a critical aspect of developing reliable communication systems. The subsequent sections of this article delve into the design process, discussing various considerations and methodologies, with the ultimate goal of achieving high-performance wireless communication in autonomous driving applications.

In addition to the section of introduction, this paper consists of six sections. Section 2, focuses on the related works of previous studies. Section 3, introduces the equations of the design of microstrip patch antenna. Section 4, shows the design and simulation of 1x2 and 1x4 antenna arrays. Section 5 discusses the results of the simulation. Section 6 presents the fabricated 1x4 antenna array and its measurement results, and finally, section 7 is the conclusion on the main findings of this work.

2. LITERATURE REVIEW

Many studies have been conducted by scholars concerned with different designs of antenna arrays with various numbers of elements for autonomous vehicle applications.

Yoon and Seo [20] introduced a 2×2 U slot patch antenna autonomous array that was specifically designed for a resonant frequency of 28 GHz. They utilized a line feed technique, resulting in a gain of 14.3 dBi. In [21], a single magnetic current radiation microstrip antenna model was developed, extending the beam width of the element to over 170◦. Similarly, the wire antenna unit discussed in [22] demonstrated a respectable beam width performance of 150◦ based on the same design concept. However, this approach often leads to a significant degradation of the cross-polarization level in the H-plane. The H-plane cross-polarization levels in both [21] and [22] exceed −10 dB. While it is possible to mitigate the high cross-polarization by shorting the two end edges of the patch [23], this would increase the patch size, limiting its application in line array configurations. A vertical linear array aligns perfectly with the requirements of SRR systems.

Furthermore, the enhancement of beam width performance in microstrip antennas can also be achieved by introducing a parasitic structure. In a study referenced as [24], the use of a parasitic loop resulted in a beam width performance improvement of up to 130◦. By incorporating two I-shaped parasitic elements adjacent to the main patch, a three-element subarray was established, as described in [25], leading to an extension of the beam width to 138◦. While this method can partially meet the requirements of SRR systems by expanding the horizontal plane beam width, it also increases the width of the microstrip unit, making it unsuitable for systems with multiple receiving antennas. For multi-receiving systems, the distance between adjacent receiving antennas must be less than $1/2\lambda 0$ (where $\lambda 0$ is the free-space wavelength at the working frequency) to avoid angle resolution errors with multiple solutions, as explained in [26]. Additionally, [18] developed a four-element antenna array operating at 28 GHz, achieving a gain of 12.2 dBi and a bandwidth of 0.9 GHz. Meanwhile, in paper [27], a rectangular patch antenna array with a gain of 11.2 dBi and a coaxial feed for antenna feeding was proposed. Arizaca-cuticula et al.

[28] also presented a beam-steering antenna array with 10 elements, operating at a resonant frequency of 28 GHz and providing a gain of 16.5 dB, despite the large size of the antenna and its feeding through a microstrip line.

Our study aims to design high-performance, low-cost, compact-size antenna designs at 5.8 GHz operating within autonomous vehicle applications and meet the requirements that need this application.

3. Design of Single Patch Antenna

The selection of the rectangular patch antenna as the antenna geometry is based on its ability to yield improved outcomes. The parameters of the antenna are determined through the application of the antenna equation.

$$W = \frac{c}{2\, f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

where, fr = Resonant frequency

c = Velocity of light

εr = Substrate dielectric constant

Antenna length calculated by,

$$LL = L_{eff} - 2\Delta L \tag{2}$$

The effective length L_effand its deviation is calculated by using the equation.

$$L_{eff} = \frac{c}{2 f_r \sqrt{\varepsilon_{reff}}} \tag{3}$$

$$\Delta L = 0.412h \frac{\left(\varepsilon_{eff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{eff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \tag{4}$$

The feeding method plays a vital role in the design of antennas by preventing any reflection from the antenna, thus enhancing its efficiency. This is accomplished by ensuring proper impedance matching in the feed line. The inset feed technique yields maximum gain and minimum return loss. The notch gap and inset feed depth are determined by (5) and (6).

$$\mathrm{Fi} \approx = \frac{0.822 \times \mathrm{Lp}}{2} \tag{5}$$

$$\mathrm{Gap} \approx \frac{c}{\sqrt{2\varepsilon_{eff}}} \ \mathrm{x} \ \frac{4.65 \times 10^{-12}}{\mathrm{f_r}} \tag{6}$$

Width of 50Ω feed line calculated by (7):

$$\mathrm{Wf} \approx \frac{120\pi}{\sqrt{\varepsilon_{eff}}\,\left(1.393 + \frac{\mathrm{Wp}}{\mathrm{h}} + \frac{2}{3}\ln\left(\frac{\mathrm{Wp}}{\mathrm{h}} + 1.444\right)\right)} \tag{7}$$

The dimensions of a single antenna ground plane can be determined using equations (8) and (9), where the width of the ground is denoted as Wg and the length of the ground is denoted as Lg.

$$W_g \approx 6.h + W_p \tag{8}$$

$$L_g \approx 6.h + L_p \tag{9}$$

The selection of the Roger RT5880 substrate material was based on its low dielectric constant, which contributes to higher directivity and cost-effectiveness. The substrate has a dielectric constant of 2.2 and a loss tangent of 0.0009. Figure 1 illustrates the frontal perspective of an individual antenna.

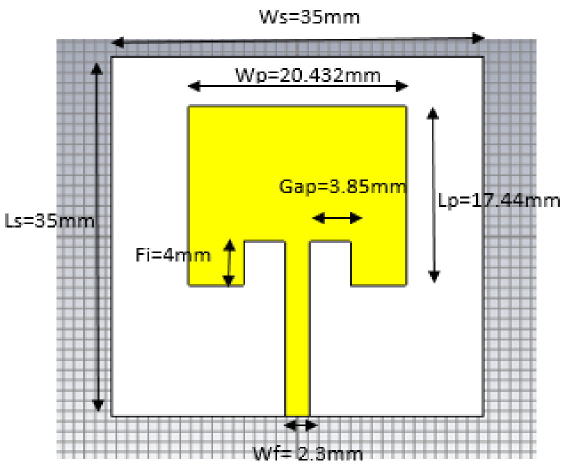


Fig.1 Single microstrip patch antenna.

4. Design of Patch Antenna Array

We have formulated a configuration of multiple antennas (array antenna) with the purpose of attaining a high level of directivity and amplification. A front view of a 1x2 antenna is shown in figure 2. As operating frequency increases, attenuation from fog, clouds, and rain rises exponential as was previously mentioned, increasing antenna gain can solve the issue. For this reason, we have created a 1×4 microstrip patch antenna. The antenna array's front view is depicted in figure 3.

As seen in figures 2 and 3, the network that links the antennas to the input port where each element is fed in parallel from a single source was designed using parallel feed technology. There is a linear arrangement among the components. The various antenna components can be arranged so that they are in a straight line from one end to the other. This indicates that the various components are arranged in a single line behind one another.

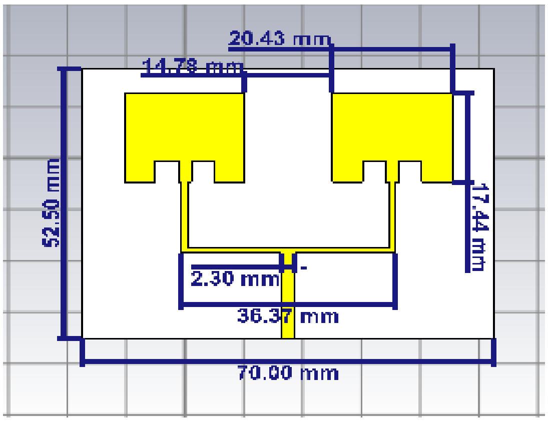


Fig.2 1x2 Patch Antenna Array

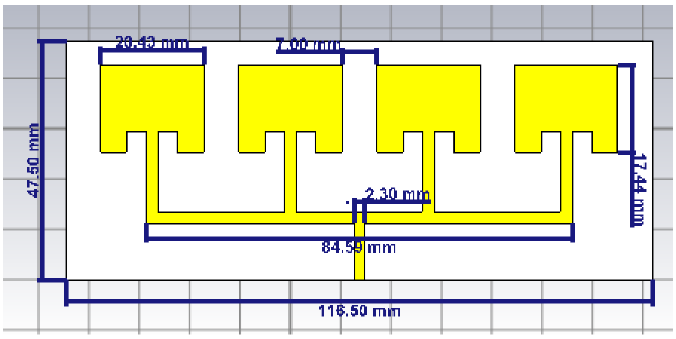


Fig.3 1x4 Patch Antenna Array

5. Results and Discussion

In this section, the antenna return loss and the voltage standing wave ratio (VSWR), radiation pattern, gain and directivity are analysed and discussed.

5.1 Return-loss

A plot known antenna return loss, or S11 parameter, uses a dB unit to represent the ratio of the incident power to the reflected power. Simultaneously, it indicates the degree of antenna matching with the transmission line or device; the higher the match, the less the return loss. The return loss plots of the 1x2 and 1x4 antenna arrays, which are -14 dB and -26 dB, respectively, are displayed in figure 4. It makes clear that radiation at the resonant frequency is both high and perfectly acceptable. Figure 4 shows the difference between antennas in terms of reflection coefficient.

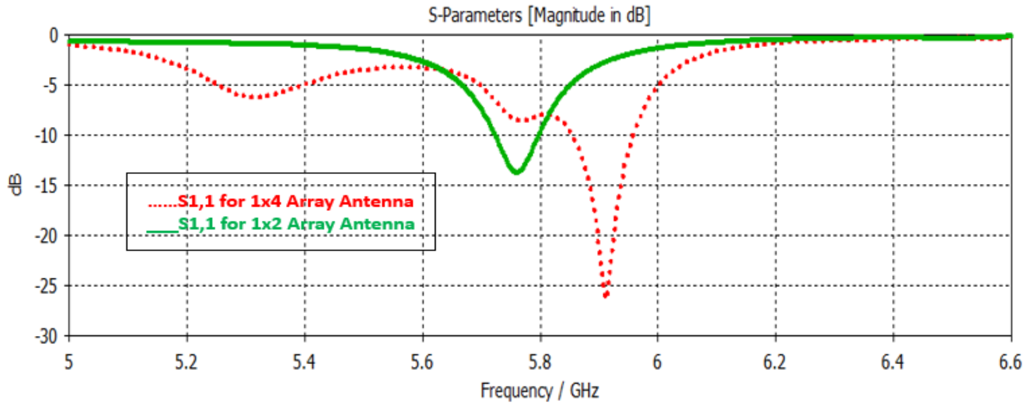


Fig.4 Return Loss of 1x2 and 1x4 Array Antenna

5.2 Voltage Standing Wave Ratio (VSWR)

The VSWR parameter, which takes the ratio of the maximum and minimum reflected voltage wave, assesses how well the antenna's impedance matches the transmission line. VSWR ≤ 2 is the primary prerequisite. The VSWR values of the 1x2 and 1x4 antenna arrays that are suggested in this work are 1.5, and 1.1, respectively. 1x4 antenna shows better result than 1x2 antenna.

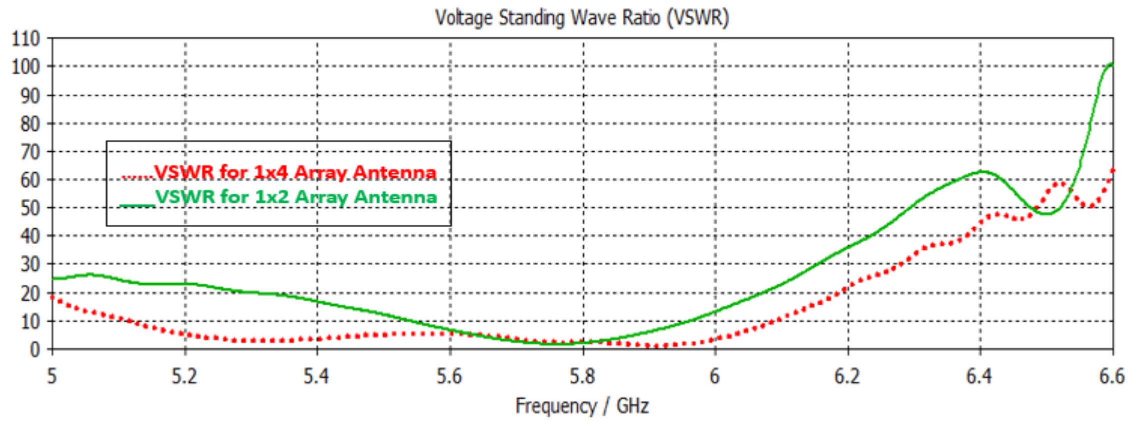


Fig.5 VSWR of 1x2 and 1x4 Array Antenna

5.3 2D-Polar Radiation Patterns

The 2D polar radiation patterns at resonant frequency is presented in figures 6and 7. The side lobe levels are -14.7 dB and -16.2 dB for 1x2 and 1x4 antenna arrays respectively.

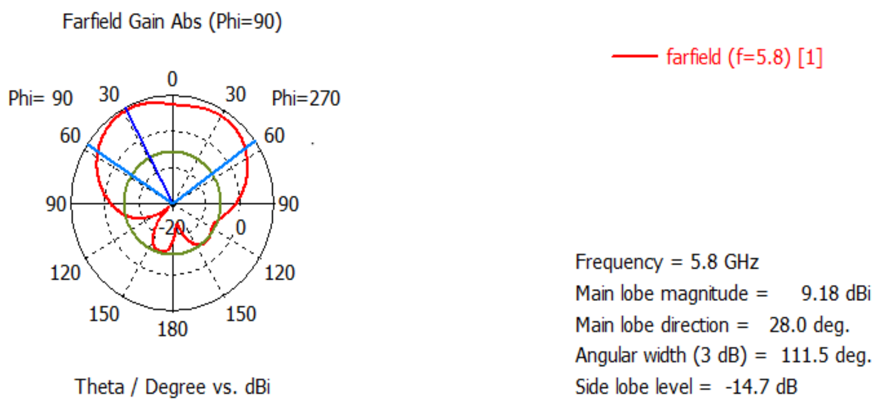


Fig.6 2D-Polar Radiation Patterns of 1x2 Array Antenna

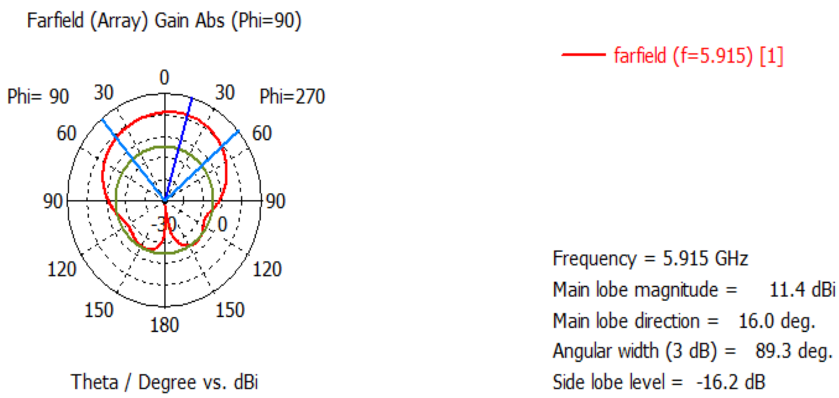


Fig.7 2D-Polar Radiation Patterns of 1x4 Array Antenna

5.4 3D Gain Plot

The measurement of an antenna's ability to convert energy into radio waves in a specific direction is called an antenna gain. Figures 8, 9 show the gain radiation patterns of the suggested antenna array design, Where the gain for 1x2 and 1x4 antenna arrays, they are 9.16 dBi and 11.4 dBi, respectively. The results obtained are good values for patch antenna arrays intended for use in applications involving autonomous vehicles.

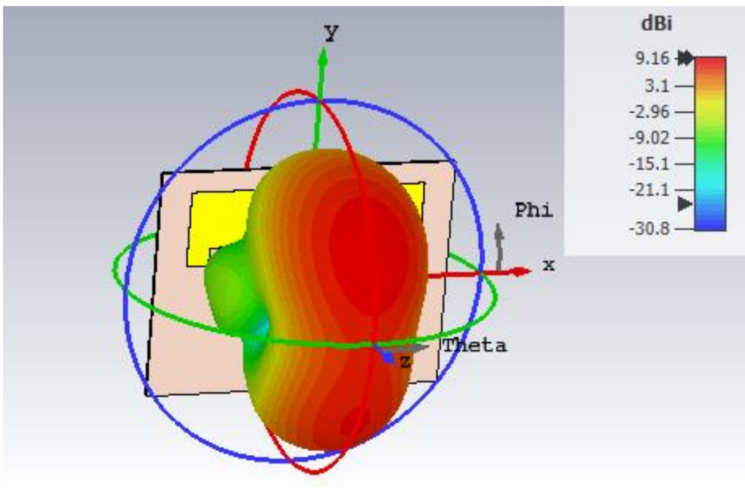


Fig.8 3D Gain of 1x2 Antenna Array

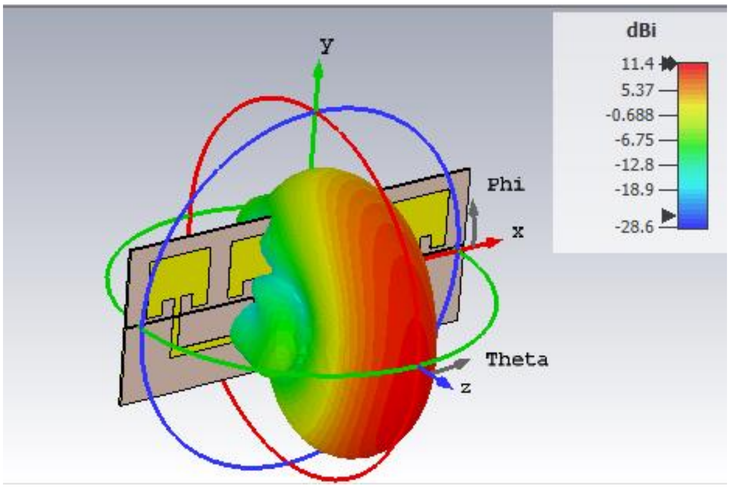


Fig.9 3D Gain of 1x4 Antenna Array

5.5 3D Directivity Plot

An essential antenna parameter is antenna directivity. It is a measurement of the radiation pattern's degree of "direction" of an antenna. The directivity of an antenna with uniform radiation in all directions would be 1 (or 0 dB), and it would have practically zero directionality. and the corresponding values for patch antenna arrays for these designs are 9.66 dBi and 12 dBi, which are excellent values.

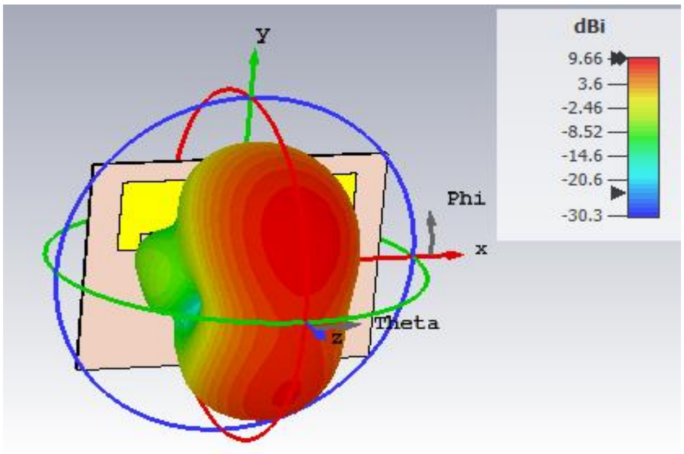


Fig.10 3D Directivity of 1x2 patch Antenna Array

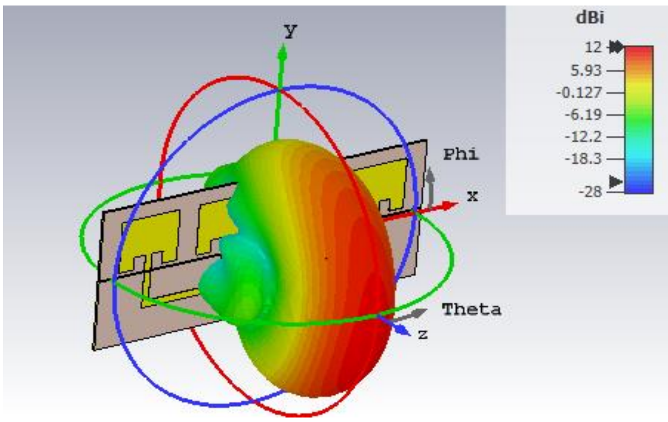


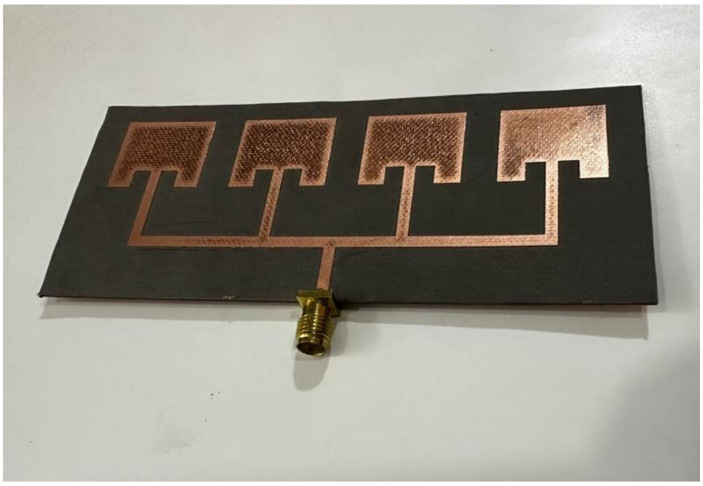
Fig. 11 3D Directivity of 1x4 patch Antenna Array

Table 1. Patch Antenna Array comparison in terms of simulation

parameter	1x4 patch Antenna Array	1x2 patch Antenna Array	unit
Return-loss	-26	-14	dB
VSWR	1.1	1.5	
2D-Polar Radiation Patterns	-16.2	-14.7	dB
3D Gain Plot	11.4	9.16	dBi
3D Directivity Plot	12	9.66	dBi

6. Fabrication and Measurement of Microstrip Patch Antenna Array

A microstrip1x4 patch antenna array was constructed using the Rogers RT/Duroid 5880 substrate. The substrate of antenna has a thickness of 0.8 mm and a tangent loss of 0.0009. The upper and lower views of the manufactured microstrip patch antenna can be seen in Figures 12 (a) and 12 (b) respectively.



(a)

(b)

Fig.12 (a) Upper and (b) Lower views of the manufactured Microstrip Patch antenna

The suggested microstrip patch antenna array was measured using the Keysight Agilent Technologies E5071C Vector Network Analyzer. Figure 13 displays a fictitious Return loss measured result. The measured outcomes agree well with the outcomes of the simulation, where it equals -26.672 dB. Both in simulation and measurements, the proposed antenna exhibits good performance.

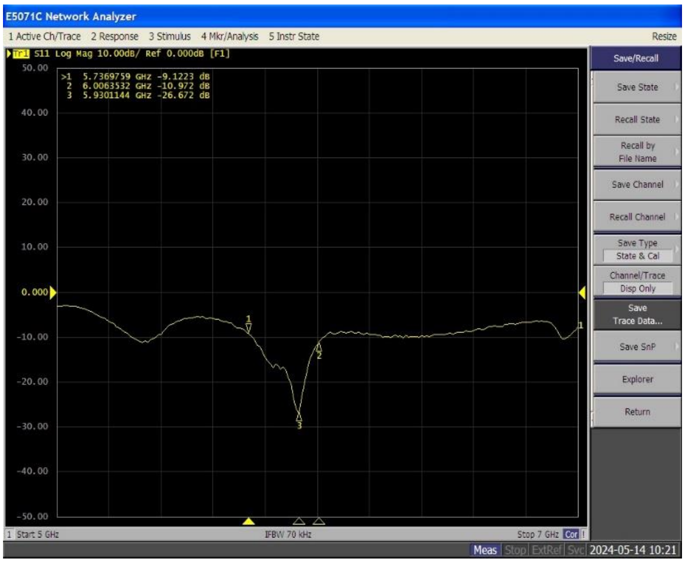


Fig.13 Measured Return Loss against frequency for the proposed microstrip antenna array

5. CONCLUSIONS

The utilization of Unmanned Aerial Vehicles (UAVs) for wireless communication is not a frequent practice, but rather, it is utilized for delivering emergency aid in case of accidents. Due to the fact that antennas resonate in a specific direction, this work suggests the use of two small-sized (1x2 and 1×4) antenna arrays to enhance the directivity of patch antenna, and this were resulted in both simulated and fabricated antennas, where the proposed antennas present results by means of return losses (the fabricated 1x4 array antenna has a return loss of -26.672 dB). The high directivity of the antenna not only improves its coverage but also lessens co-channel interference with nearby UEs or UAVs, allowing for seamless UAV deployment over the 5G network. Additionally, a smaller size will save fabrication costs and allow the UAV to attach more payloads. The design of antenna arrays for autonomous vehicles has been found to achieve high gain and directivity in the proposed work.

REFERENCES

1. Hasch, J., et al., *Millimeter-wave technology for automotive radar sensors in the 77 GHz frequency band.* IEEE transactions on microwave theory and techniques, 2012. **60**(3): p. 845-860.
2. Patole, S.M., et al., *Automotive radars: A review of signal processing techniques.* IEEE Signal Processing Magazine, 2017. **34**(2): p. 22-35.
3. Hashim, W.M. and A.H. Sallomi, *Broadband Microstrip Antenna for 2G/3G/4G Mobile Base Station Applications.* Al-Qadisiyah Journal for Engineering Sciences, 2018. **11**(2): p. 165-175.
4. Hassan, S.K., A.H. Sallomi, and M.H. Wali. *New Design and Analysis Microstrip Triple Band-Notched UWB of Monopole Antenna*. in *2022 International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA)*. 2022. IEEE.
5. Khan, O., et al., *Hybrid Thin Film Multilayer Antenna Automotive Radar at 77 GHz.* 2018.
6. Wei, W. and X. Wang, *A 77 GHz series fed weighted antenna arrays with suppressed sidelobes in E-and H-plane.* Progress In Electromagnetics Research Letters, 2018. **72**: p. 23-28.
7. Tawfeeq, N.N. and A.H. Sallomi, *Gain Improvement of Millimetre-Wave Two Element Array Antenna for 5G Networks by Using Frequency-Selective Surface-based Reflector.* International Journal of Intelligent Engineering & Systems, 2024. **17**(5).
8. Khazaal, H.F., et al., *Fabrication and Testing of Pyramidal X-Band Standard Horn Antenna.* 2018. **26**(1): p. 298-305.
9. Khazaal, H.F., H.T.S. ALRikabi, and M.S. Farhan, *EVALUATION OF THE EFFECT OF LENGTH ON THE PERFORMANCE OF RECTANGULAR TO RECTANGULAR WAVEGUIDE TAPER.* Al-Qadisiyah Journal for Engineering Sciences, 2017. **10**(4): p. 536-549.
10. Yasini, S., K. Mohammadpour-Aghdam, and M. Mohammad-Taheri, *Low-cost comb-line-fed microstrip antenna arrays with low sidelobe level for 77 GHz automotive radar applications.* Progress In Electromagnetics Research M, 2020. **94**: p. 179-187.
11. Kuriyama, A., et al. *A high efficiency antenna with horn and lens for 77 GHz automotive long range radar*. in *2016 46th European Microwave Conference (EuMC)*. 2016. IEEE.

12. ALRikabi, H., et al., *Reconfigurable Intelligent Surfaces Between the Reality and Imagination.* Wasit Journal of Computer and Mathematics Science, 2024. **3**(2): p. 42-50.
13. Qasim, A.A.-K. and A.H. Sallomi, *Rabid Euclidean direction search algorithm for various adaptive array geometries.* Bulletin of Electrical Engineering and Informatics, 2021. **10**(2): p. 856-869.
14. Yoo, S., et al., *Patch array antenna using a dual coupled feeding structure for 79 GHz automotive radar applications.* IEEE Antennas and Wireless Propagation Letters, 2020. **19**(4): p. 676-679.
15. Wang, N., et al. *The design of 77 GHz microstrip antenna array applied to automotive anti-collision radar antenna*. in *2019 IEEE Asia-Pacific Microwave Conference (APMC)*. 2019. IEEE.
16. Lee, J.-H., J.M. Lee, and K.C. Hwang. *Series feeding rectangular microstrip patch array antenna for 77 GHz automotive radar*. in *2017 International Symposium on Antennas and Propagation (ISAP)*. 2017. IEEE.
17. Kim, Y.-B., et al., *Compact planar multipole antenna for scalable wide beamwidth and bandwidth characteristics.* IEEE Transactions on Antennas and Propagation, 2020. **68**(5): p. 3433-3442.
18. Kim, Y.-B., S. Lim, and H.L. Lee, *Electrically conformal antenna array with planar multipole structure for 2-D wide angle beam steering.* IEEE Access, 2020. **8**: p. 157261-157269.
19. Hasan Fahad KHazaal, Ahmed Magdy, Iryna Svyd, IVAN OBOD, *A Dumbbell Shape Reconfigurable Intelligent Surface for mm-wave 5G Application.* International Journal of Intelligent Engineering and Systems, 2024. **17**(6): p. 569-582.
20. Yi, Z., et al., *A wide-angle beam scanning antenna in E-plane for K-band radar sensor.* IEEE Access, 2019. **7**: p. 171684-171690.
21. Liu, C.-M., et al., *Wide-angle scanning low profile phased array antenna based on a novel magnetic dipole.* IEEE Transactions on Antennas and Propagation, 2017. **65**(3): p. 1151-1162.
22. Liu, C.-M., S. Xiao, and X.-L. Zhang, *A compact, low-profile wire antenna applied to wide-angle scanning phased array.* IEEE Antennas and Wireless Propagation Letters, 2018. **17**(3): p. 389-392.
23. Liu, N.-W., et al., *Dual-band single-layer microstrip patch antenna with enhanced bandwidth and beamwidth based on reshaped multiresonant modes.* IEEE Transactions on Antennas and Propagation, 2019. **67**(11): p. 7127-7132.
24. Yu, C.-A., et al., *24 GHz horizontally polarized automotive antenna arrays with wide fan beam and high gain.* IEEE transactions on antennas and propagation, 2018. **67**(2): p. 892-904.
25. Bryant, B., Y.-K. Hong, and H. Won. *Triple-band (Dedicated short-range communication, 5G, 6G) antenna for vehicle telematics*. in *2022 IEEE Radio and Wireless Symposium (RWS)*. 2022. IEEE.
26. Foysal, M.F., S. Mahmud, and A. Baki. *A novel high gain array antenna design for autonomous vehicles of 6g wireless systems*. in *2021 International Conference on Green Energy, Computing and Sustainable Technology (GECOST)*. 2021. IEEE.
27. Xu, J., W. Hong, and H. Zhang. *Low-Profile Patch Array Antenna with Stable Beam for 77 GHz Automotive Radar Applications*. in *2019 International Symposium on Antennas and Propagation (ISAP)*. 2019. IEEE.
28. N. Ram, G.H., M. S. Sadiq and A. Chand Bahadur. *Parrall Feed Microstrip Antenna Array for the Applications of Automotive vehicles*. in *th Asia-Pacific Conference on Antennas and Propagation (APCAP)*. 2020. Xiamen, China.