Scientific Research Publishing

World Journal of Engineering and Technology, 2023, 11, 293-302
https://www.scirp.org/journal/wjet
ISSN Online: 2331-4249
ISSN Print: 2331-4222

Design of a High-Gain 2 × 1 Array Antenna for S-Band Applications

Md. Imran Hossain[1]*, Md. Ariful Islam[2], Md. Tofail Ahmed[3], Md. Humaun Kabir[4]

[1]Department of Electrical, Electronic and Communication Engineering, Pabna University of Science and Technology, Pabna, Bangladesh
[2]Department of Electrical and Electronic Engineering, Pabna University of Science and Technology, Pabna, Bangladesh
[3]Department of Information and Communication Engineering, Pabna University of Science and Technology, Pabna, Bangladesh
[4]Department of Computer Science and Engineering, Bangamata Sheikh Fojilatunnesa Mujib Science & Technology University, Jamalpur, Bangladesh
Email: *imranete.pust@gmail.com, arif.eee@pust.ac.bd, tofail.ru@pust.ac.bd, humaun@bsfmstu.ac.bd

How to cite this paper: Hossain, Md.I., Islam, Md.A., Ahmed, Md.T. and Kabir, Md.H. (2023) Design of a High-Gain 2 × 1 Array Antenna for S-Band Applications. *World Journal of Engineering and Technology*, **11**, 293-302.
https://doi.org/10.4236/wjet.2023.112021

Received: March 2, 2023
Accepted: May 9, 2023
Published: May 12, 2023

Abstract

Antennas are an indispensable element in wireless networks. For long-distance wireless communication, antenna gains need to be very strong (highly directive) because the signal from the antenna loses a lot of strength as it travels over long distances. This is true in the military with missile, radar, and satellite systems, etc. Antenna arrays are commonly employed to focus electromagnetic waves in a certain direction that cannot be achieved perfectly with a single-element antenna. The goal of this study is to design a rectangular microstrip high-gain 2 × 1 array antenna using ADS Momentum. This microstrip patch array design makes use of the RT-DUROID 5880 as a substrate with a dielectric constant of 2.2, substrate height of 1.588 mm, and tangent loss of 0.001. To achieve efficient gain and return loss characteristics for the proposed array antenna, RT-Duroid is a good choice of dielectric material. The designed array antenna is made up of two rectangular patches, which have a resonance frequency of 3.3 GHz. These rectangular patches are excited by microstrip feed lines with 13 mm lengths and 4.8 mm widths. The impedance of the patches is perfectly matched by these transmission lines, which helps to get better antenna characteristics. At a resonance frequency of 3.3 GHz, the suggested antenna array has a directivity of 10.50 dB and a maximum gain of 9.90 dB in the S-band. The S parameters, 3D radiation pattern, directivity, gain, and efficiency of the constructed array antenna are all available in ADS Momentum.

Keywords

Microstrip Patch Antenna, Array Antenna, Microstrip Feed, Rectangular Patch, Gain, Efficiency, Directivity, ADS

1. Introduction

Microstrip antennas' unique and appealing properties have led to their widespread adoption and use in a wide variety of contexts, including but not limited to Mobile, Microwave Engineering, Satellite Communication, and Aircraft Systems [1]. Long-distance communication, such as mobile, radar, and satellite, suffers from more propagation loss than short-distance communication [2] [3]. As a result, the antenna used in long-distance communication must have high gains, excellent directivity, a wide bandwidth, and fast data transfer. Many antenna studies have been conducted in order to meet these requirements. As a result, many antenna designers have focused their efforts in recent years on improving the properties of these antennas. The bandwidth and gains of the array antennas have improved [4] [5] [6]. In [7], the design, construction, and testing of a cost-effective slotted microstrip line-fed antenna array with a shorted patch to the ground plane prototype are shown. Kamei *et al.* [8] developed a 4-element geometric array antenna out of four 20 GHz band patch antennas. The structure of the linear array antenna enables the wave to be fed to the patch antennas without interaction from open-end coplanar waveguides. Additionally, Kamei *et al.* [8] conducted research on the factors associated with the construction of a linear array radiating patch. The paper [9] talks about a beam-steering antenna array that keeps its pattern the same even when the frequencies change. Mousavi *et al.* [10] show their work, which is the Butler matrix feeder network approach to building a deformation array antenna. In [11], there are two different types of the Butler structure, each with a different set of slots radiating elements (4 × 4 and 2 × 4). In [12], a rectangular microstrip patch antenna with an air cavity is shown and theoretically evaluated as a means of achieving high gain and an enhanced front-to-back ratio on a standard poly tetra fluoro ethylene (PTFE) substrate. The authors of [13] print the metamaterial on both sides of the substrate material to get a wide frequency range and high gains. Microstrip array antennas constructed on a FR4 substrate are described in [14]; they are revolutionary due to their small size and potential use in Ku band satellite applications. Patch antennas made of microstrip are preferred because their primary benefits include a low-profile planar arrangement array antenna, in addition to their low weight and minimal space [15]-[22]. One method by which the performance of an antenna array can be enhanced is by adding a larger number of array elements [23] [24]. The increase in cost, size, and complexity that follows an increase in the number of elements [25] [26] [27] is an undesirable side effect. In this paper, we attempt to achieve maximum gain by selecting proper dielectric materials, using the two elements of array, and setting the permissible range of separation distance between the patches. For the design, we also concentrated on the shapes of the antenna patch and the feeding technique. Then, we used ADS, a platform for software that simulates electromagnetic fields, to do optimization and get the best results. So, this article is divided into two major sections: the design section and the simulated result section of the proposed array antenna. In the design section, we discussed the structure of the patch, the importance of the substrate and its characteristics, the patch's description, the feed line's detail, and their respective parameter values. In the simulation result section, we observed the radiation pattern characteristics (return loss graph, gain, directivity, smith chart, and efficiency) of the proposed array antenna and also described these terms with respect to the array antenna. Finally, the conclusion part of this article concludes the array antenna from the findings of the simulated result of ADS.

2. Design of Antenna Arrays

Advance Design System (ADS) momentum is used to connect the two antenna elements that make up the patch pattern into an array. In a patch antenna, the patch, which has a specific length and width, is the radiating element that radiates an electromagnetic wave. The ratio of patch width to length determines the antenna's resonance frequency. The resonant frequency is the operating frequency of the patch antenna. At this frequency, the antenna radiates with minimum power loss in the antenna system. Some common antenna shapes are square, triangle, hexagon, circle, elliptical, etc. A patch antenna can be made in any shape that is continuous. Through their unique design, rectangular patch antennas can be taken apart. It is also easy to analyse an antenna, which is why we prefer rectangular patches. The design makes use of RT/Duroid 5880 as a substrate material. RT/Duroid 5880 have a low dielectric constant and low tangent loss, making them well adapted to high-frequency and broadband applications. High frequency PTFE composites that are strengthened with glass microfibers are what RT/Duroid 5880 laminates are made of. The randomly aligned microfibers reinforcing the PTFE composites help to preserve the dielectric constant homogeneity [28]. **Table 1** shows the design variables and their values for the 2 × 1 array.

This microstrip patch array is fed by individual elements using quarter-wave microstrip lines. A microstrip feed line is a thick transmission line of specific length and width, and its function is to connect the antenna to the receiver or transmitter. There are various kinds of feeding techniques, such as microstrip line feeding, coaxial feeding, aperture coupling, and proximity coupling. With microstrip lines, it is feasible to use quarter-wave transformers to feed the patch components and match their input impedance. For a particular characteristic impedance of a microstrip feed line, the width and length of the feed line will vary depending on the dielectric material used. As shown in **Figure 1**, all two patch sections are linearly arranged with a precise power diving circuit to match the impedance. The present model of array antennas maximizes both gain and efficiency. For this purpose, we select an x-axis alignment and a component separation that will allow us to achieve high gain of array antenna that is our goal. In this instance, the separation distance is set to 0.91 λ (83.6 millimeters), and the array receives its input from a line that is 3.5 millimeters wide and 19 millimeters long. **Figure 1** depicts the arrangement of a 2 × 1 rectangular patch array antenna.

Table 1. Design parameters and respective values of the array antenna.

Serial	Design Parameters	Parameter Values
1	Length of the single patch	29.5 mm
2	Width of the single patch	42.5 mm
3	Patch depth	0.02 mm
4	Dielectric Constant	2.2
5	Height of Substrate	1.588 mm
6	Tangent Loss	0.001
7	Separation distance between patches	83.6 mm
8	Length of single patch feed line	13 mm
9	Width of single patch feed line	4.8 mm

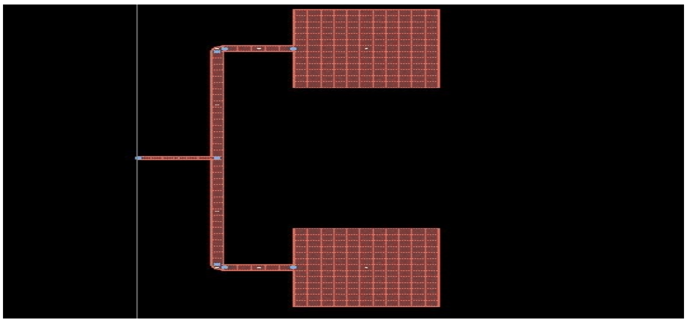

Figure 1. 2 × 1 rectangular patch antenna array.

3. Simulated Result of Patch Array Antenna

Here we will go through some of the most significant findings with regards to the suggested array antenna. We look at the antenna structure's simulated S11 characteristics, radiation characteristics, antenna gain, and other important antenna metrics like efficiency and bandwidth.

3.1. 3D Far Field Radiation Pattern

An illustration of the 2 × 1 array field radiation profile in the E-plane is shown in Figure 2. In order to know how much energy an antenna emits and how it changes as we go further away from it, we should look at its radiation pattern. This difference in power with respect to arrival angle is very clear in the antenna's far field. The main lobe beam's width typically decreases with increasing element separation. Gate lobes (non-primary lobe maximum) are introduced when the element separation is greater than or equal to one wavelength. If no grating lobes are desired in the array pattern, the array element spacing must be less than one wavelength. So, in this design we use separation distance of 0.91 λ (83.6 millimeters). It can be seen that the beam width becomes more focused as the number of arrays increases, as measured by the broadside array factor [27]. The antenna array is emitting broadside, or perpendicular to the patch's axis. In Figure 2, between 0˚ and 180˚, the main beam is sharp and indicates that array antenna directs sharply perpendicular to the patch's axis. This graph demonstrates that the design is effective and that the anticipated results were obtained.

3.2. Return Loss

As seen in **Figure 3**, the 2 × 1 microstrip array antenna design has a reflection coefficient of S11. Because the reflected signal moves in the opposite direction of the initial signal, there will be points along the cable where the signals are in phase and sites where the signals are out of phase because of the imbalance between the antenna and the transmitter. This phenomenon, known as VSWR (voltage standing wave ratio), will cause standing waves to form in the transmission line. Usually, the term "return loss" is used to describe the sources of the input and output signals. The lowest value of S11 of the array antenna is approximately −49.29 dB at the frequency of 3.30 GHz, as shown in **Figure 3**. For this, we look at **Figure 4**, which shows how the phase changes as the frequency changes.

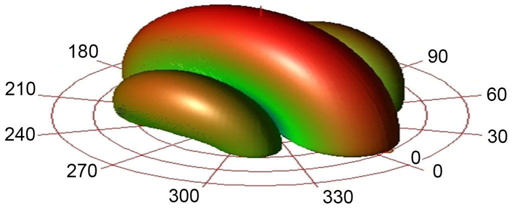

Figure 2. 3D far field radiation plot of 2 × 1 rectangular patch antenna array.

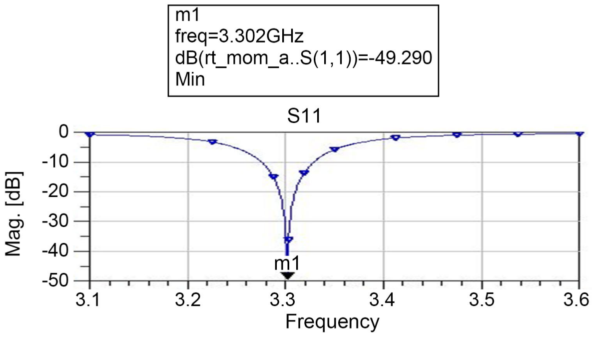

Figure 3. S11 graph of array antenna.

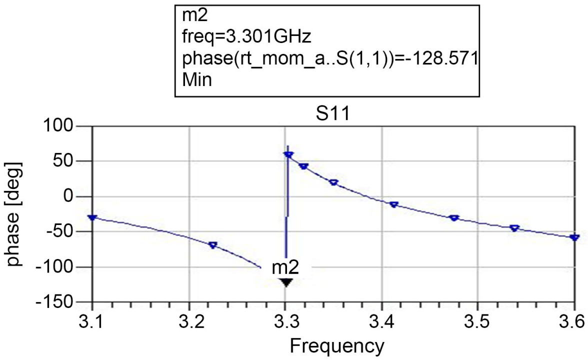

Figure 4. Phase vs. frequency curve.

3.3. Gain and Directivity of Array Antenna

An antenna's gain (G) is directly related to its directional performance (D). The term "directivity" describes the degree to which an antenna favors transmitting power along one route over others. **Figure 5** shows the gain and directivity curves of the array at the resonating frequency. At the resonance frequency, the antenna array has a directivity of 10.50 dB, a gain of 9.90 dB, and stable radiation performance. Improving gain and directivity while keeping radiation characteristics to a minimum was the main focus throughout the antenna array. The gain and directivity of a single patch antenna were reported to be 7.59 dB and 7.70 dB, correspondingly, in [28]. The proposed design features an impressive 10 dB or more of directional selectivity in the desired direction, together with a high gain.

3.4. Smith Chart Result

It can be noticed in **Figure 6** that ADS Momentum's curve corresponds to the Smith chart's curve for the input coefficient of reflection. At its lowest resistance which corresponds to the array antenna's resonance frequency of 3.30 GHz, as shown in the Smith plot. The lowest impedance point of the antenna, denoted by the m^{3} marker, is likewise located there. The antenna has an impedance of RA = Zo (1.002 + j0.007) ohm, as calculated using the Smith chart.

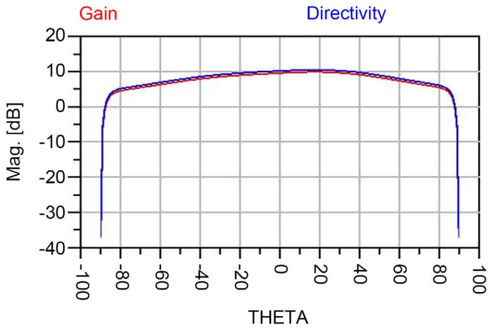

Figure 5. Gain and directivity graphs.

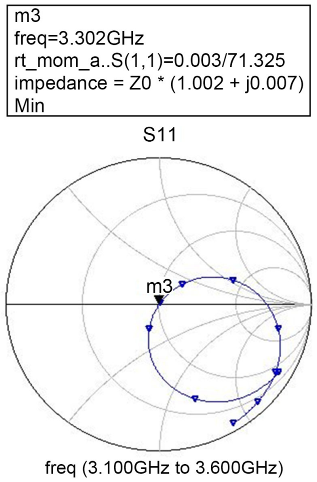

Figure 6. Smith chart result of array antenna.

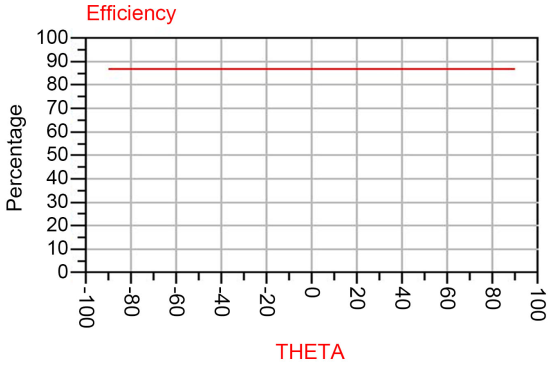

Figure 7. Efficiency of the array antenna.

3.5. Efficiency

Figure 7 depicts the efficiency of this antenna. The array antenna has 88.25% efficiency.

4. Conclusion

At the appropriate frequency of operation, the proposed model exhibits outstanding gain (9.90 dB) and radiation characteristics. More than 88% radiation efficiency and 10.50 dB of directivity are also attained with the existing layout. In [28], the gain and directivity were 7.59 dB and 7.70 dB, respectively, for a single patch antenna at 3.3 GHz Frequency and using RT-Duroid 5880 as dielectric material. The results of all of these simulations point to the same conclusion, which is that the gain and directivity of an antenna are exactly proportional to the number of patches contained inside an array. The microstrip patch array antenna that has been proposed can successfully be utilized in vehicle satellite communication and automotive radar systems to collect electromagnetic energy in the 3.3 GHz range (S-Band). So, the proposed concept is suitable for S-band applications requiring high gain while utilizing minimal power. For the purpose of future study, a microstrip array antenna that makes use of 2 × 2 array elements has the potential to significantly improve its gain, directivity, radiation pattern, and efficiency.

Acknowledgements

Words cannot express my gratitude to my parents and colleagues of my university for their invaluable patience and feedback. I also could not have undertaken this journey without my teachers, who generously provided knowledge and expertise. Additionally, this endeavor would not have been possible without the generous support from my supervisor, who guideline me to do my research.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Gupta, M., Sachdeva, S., Swamy, N.K. and Singh, I.P. (2014) Rectangular Microstrip Patch Antenna Using Air as Substrate for S-Band Communication. *Journal of Electromagnetic Analysis and Applications*, **6**, 38-41. https://doi.org/10.4236/jemaa.2014.63006

[2] Liu, D., Gu, X., Baks, C.W. and Garcia, A.V. (2017) Antenna-in-Package Design Considerations for Ka-Band 5G Communication Applications. *IEEE Transactions on Antennas and Propagation*, **65**, 6372-6379. https://doi.org/10.1109/TAP.2017.2722873

[3] Zhu, S., Liu, H., Chen, Z. and Wen, P. (2018) A Compact Gain-Enhanced Vivaldi Antenna Array with Suppressed Mutual Coupling for 5G mmWave Application. *IEEE Antennas and Wireless Propagation Letters*, **17**, 776-779. https://doi.org/10.1109/LAWP.2018.2816038

[4] Yoon, N. and Seo, C. (2017) A 28-GHz wideband 2 × 2 U-Slot Patch Array Antenna. *Journal of Electromagnetic Engineering and Science*, **17**, 133-137. https://doi.org/10.5515/JKIEES.2017.17.3.133

[5] Park, S.J., Shin, D.H. and Park, S.O. (2016) Low Side-Lobe Substrate-Integrated-Waveguide Antenna Array Using Broadband Unequal Feeding Network for Millimeter-Wave Handset Device. *IEEE Transactions on Antennas and Propagation*, **64**, 923-932. https://doi.org/10.1109/TAP.2015.2513075

[6] Ta, S.X. and Park, I. (2016) Cavity-Backed Angled-Dipole Antennas for Millimeter-Wave Wireless Applications. *International Journal of Antennas and Propagation*, **2016**, Article ID: 5083807. https://doi.org/10.1155/2016/5083807

[7] Bidkar, G., Vani, R. and Hungund, P. (2013) Design and Development of a 2 × 1 Array of Slotted Microstrip Line Fed Shorted Patch Antenna for DCS Mobile Communication System. *Wireless Engineering and Technology*, **4**, 59-63. https://doi.org/10.4236/wet.2013.41009

[8] Kamei, T., Shima, H., Fukuda, S. and Ishii, S. (2017) A Linear Array Antenna of Microstrip Patch Antennas Fed by the Open-End of Coplanar Waveguides. *Wireless Engineering and Technology*, **8**, 37-49. https://doi.org/10.4236/wet.2017.82003

[9] Rafiei, V., Ghader, S., Saeid, K. and Mesut, K. (2020) Beam-Steering High-Gain Array Antenna with FP Bow-Tie Slot Antenna Element for Pattern Stabilization. *IET Microwaves, Antennas & Propagation*, **14**, 1185-1189. https://doi.org/10.1049/iet-map.2019.1071

[10] Mousavi, Z. and Pejman, R. (2019) Millimetre-Wave Beam-Steering Array Antenna by Emphasising on Improvement of Butler Matrix Features. *IET Microwaves, Antennas & Propagation*, **13**, 1287-1292. https://doi.org/10.1049/iet-map.2018.5340

[11] Alreshaid, A.T., Sharawi, M.S., Podilchak, S. and Sarabandi, K. (2016) Compact Millimeter-Wave Switched-Beam Antenna Arrays for Short Range Communications. *Microwave and Optical Technology Letters*, **58**, 1917-1921. https://doi.org/10.1002/mop.29940

[12] Malakar, K., Nandi, J., Mitra, S., Gorai, P., Chattopadhyay, S. and Banerjee, S. (2011) Rectangular Microstrip Antenna with Air Cavity for High Gain and Improved Front to Back Ratio. *Journal of Electromagnetic Analysis and Applications*, **3**, 368-372. https://doi.org/10.4236/jemaa.2011.39058

[13] Jeong, M.J., Niamat, H., Ji, W.P., Seong, G.P., Seung, Y.R. and Nam, K. (2019) Millimeter-Wave Microstrip Patch Antenna Using Vertically Coupled Split Ring Metaplate for Gain Enhancement. *Microwave and Optical Technology Letters*, **61**,

2360-2365. https://doi.org/10.1002/mop.31908

[14] Wasim, M., Shelej, K. and Malaisamy, K. (2022) High Gain and Bandwidth Array Antenna for Satellite Application. *Journal of Physics: Conference Series*, **2327**, Article 012058. https://doi.org/10.1088/1742-6596/2327/1/012058

[15] Venkat, K. and Divya, C. (2017) Design and Simulation of Common Feed with Double Microstrip Patch Antenna for Dual Band Satellite Applications. *International Journal of Engineering Research and Modern Education* (*IJERME*), **2**, 155-161. https://ssrn.com/abstract=3003038

[16] Venkatesh, K. and Divya, C. (2017) Design and Analysis of Array of Slot Antenna for S-Band Application. *International Journal of Advanced Trends in Engineering and Technology* (*IJATET*), **2**, 115-121.

[17] Malaisamy, K. and Balaji, B.K. (2016) Design of Microstrip Array Antenna for Ku-Band Applications. *International Journal of Communication and Networking System*, **5**, 29-32.

[18] Lai, H.W., Xue, D., Wong, H., So, K.K. and Zhang, X.Y. (2016) Broadband Circularly Polarized Patch Antenna Arrays with Multiple-Layers Structure. *IEEE Antennas and Wireless Propagation Letters*, **16**, 525-528.

[19] Yadav, R., Yadav, S.K. and Sharma, I.B. (2015) Reconfigurable Single and Dual Band Microstrip Patch Antenna for Satellite Communications. *IEEE* 2015 *International Conference on Green Computing and Internet of Things* (*ICGCIoT*), Greater Noida, 8-10 October 2015, 1565-1570. https://doi.org/10.1109/ICGCIoT.2015.7380716

[20] Jin, H., *et al.* (2014) Differential-Fed Patch Antenna Arrays with Low Cross Polarization and Wide Bandwidths. *IEEE Antennas and Wireless Propagation Letters*, **13**, 1069-1072. https://doi.org/10.1109/LAWP.2014.2328352

[21] Kouhalvandi, L., Selcuk, P. and Yagci, H.B. (2015) Ku-Band Slotted Rectangular Patch Array Antenna Design. *IEEE* 2015 23*nd Signal Processing and Communications Applications Conference* (*SIU*), Malatya, 16-19 May 2015, 447-450. https://doi.org/10.1109/SIU.2015.7129855

[22] Bilgic, M.M. and Yegin, K. (2014) Wideband Offset Slot-Coupled Patch Antenna Array for X/Ku-Band Multimode Radars. *IEEE Antennas and Wireless Propagation Letters*, **13**, 157-160. https://doi.org/10.1109/LAWP.2013.2296911

[23] James, J. and Hall, P. (1988) Handbook of Microstrip Antennas. IEE Electromagnetic Waves Series, Royal Military College of Music, London. https://doi.org/10.1049/PBEW028G

[24] Pozar, D. and Schaubert, D. (1995) Microstrip Antennas: The Analysis and Design of Microstrip Antennas and Arrays. Wiley-IEEE Press, New York. https://doi.org/10.1109/9780470545270

[25] Madhav, B.T.P., Pisipati, V.G.K.M., Habibulla, K., Prasad, V.G.N.S., Praveen, K.K., Bhavani, K.V.L. and Prasad, D.P.V. (2011) Microstrip 2×2 Square Patch Array Antenna on K15 Liquid Crystal Substrate. *International Journal of Applied Engineering Research*, **6**, 1099-1104.

[26] Madhav, B.T.P., Sowjanya, J., Swathi, V. and Tanmayee, P. (2014) Circular Array Antenna Synthesis Based on Element Spacing. *International Journal of Applied Engineering Research*, **9**, 6959-6965.

[27] Ramkiran, D.S., Madhav, B.T.P., Nimmagadda, H., Ramya, R.S., Vindhya, K.M. and Abhishek, S.P. (2014) Design and Analysis of Microstrip Slot Array Antenna Configuration for Bandwidth Enhancement. *Leonardo Electronic Journal of Practices and Technologies*, **25**, 72-83.

[28] Hossain, I., Ahmed, T. and Kabir, H. (2022) Design of Rectangular Microstrip Patch Antenna at 3.3 GHz Frequency for S-Band Applications. *International Journal of Engineering and Manufacturing*, **12**, 46-52. https://doi.org/10.5815/ijem.2022.04.05