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A Novel Dual-Band Orthogonal Polarized Elliptical Patch Antenna Array for 5G Applications

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Abstract: **In this article, a novel dual-band orthogonally polarized elliptical microstrip patch array antenna is presented at millimeter wave spectrum of 28 GHz and 38 GHz. For the single-element design, the acquired gain for 28 GHz is 6.81 dBi and 7 dBi for 38 GHz. The antenna is orthogonally polarized and generated orthogonal modes TM01 and TM10. To design antenna the Rogers RT/duroid 5880 substrate medium used with a permittivity ε_r of 2.2, loss tangent tanδ of 0.003, and height of 0.25 mm. To improve the performance of the antenna a four-element multilayer antenna array is designed with the coaxial to microstrip line transition and power divider network. To create a multilayer structure two layers of substrate are created at the top and bottom of the ground plane. The design is analysed by Computer Simulation Technology Microwave Studio Suite, 2018. After the simulation, the proposed antenna array provides good results as compared with the single element antenna design regarding gain, return loss, far-field pattern, bandwidth, and directivity.**

Index Terms: **28 GHz, 38 GHz, 5G, antenna array, elliptical patch.**

I. Introduction

Wireless technology is as of now among the most investigative field in communication devices. For the next generation, wireless communication systems antennas are anticipated to attain high data rate, improved gain and bandwidth, low power loss, low cost, and small in size. As because of certain constraints in fourth generation technology, like low data transmission, high path loss, and high response time, technology for wireless communication is changing from 4G to 5G network (Kumar, 2016; Hong, 2017). The limitations found in 4G can cover by fifth generation wireless technology with an increase in data rate on gigabits per second, getting latency on millisecond level, and come up with low battery consumption and low cost devices (Reddy, 2017).

To attain the new generation requirements the allocated spectrum for millimeter-wave is from 3 GHz – 300 GHz. Most of the research work was done on the 28 GHz, 38 GHz, 60GHz, and (70-80) GHz for mm-wave spectrum. The majority of the study is centered on the frequency band of 28 GHz and 38 GHz because the atmospheric absorption, oxygen loss, and rain attenuation are low as compared to the higher frequency spectrum (Niu, 2015; Rappaport, 2013; Kumar, 2018). For the fifth generation wireless systems, it is demanded that antennas provide high gain to overcome the path loss, achieve high gain, and improved efficiency at millimeter wave frequencies. Microstrip antenna is compact, lightweight, and provides easy integration with the circuits it is suitable for millimeter wave applications (Abirami, 2017; Kaur, 2016). However, microstrip antenna has some drawbacks namely low gain and narrow bandwidth (Chen, 2006; Sidhu, 2016). Research shows different approaches like array configuration, impedance matching, and slotted patch to improve gain and bandwidth (Chauhan, 2014; Rabbani, 2017). Microstrip antennas are generally utilized in the global positioning system, mobile communication system, microwave sensors, and wireless local area network (Noh, 2017).

For 5G mobile communications different patch antenna designs were presented by researchers. A double band PIFA antenna for the frequency band of 28 GHz and 38 GHz is proposed by (Ahmad, 2017) which consists of a shorted patch and a U shape slot etched within the patch. A low-cost FR406 substrate material is used to design the antenna. The acquired gain at 28 GHz and 38 GHz is 3.75 dBi and 5.06 dBi, individually. (Mpele, 2019) designed a compact dual band patch antenna with an elliptical radiating patch etched on the Rogers RO3010 substrate. Antenna fed by coplanar waveguide (CPW) feeding network, also to improve the performance of the design detected ground structure technique is used. The achieved gain for 28 GHz is 6.0 dBi and 6.3 dBi for 38 GHz. A monopole

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circular patch antenna etched with elliptical slots presented by (Gunaram, 2020). The proposed antenna developed on an FR-4 substrate has a dimension of 9.1 x 9.0 x 1.59 mm3 and operates at two frequencies of 23.1 GHz and 28 GHz. The achieved return loss for both frequencies is nearby -40 dB with a gain of 3.94 dBi and 3.76 dBi at 23.1 GHz and 28 GHz bands each. Sharaf (2020) presented a patch antenna for 5th-generation wireless communication for 38 and 60 GHz frequency ranges. For the 38 GHz band, the patch is etched on Rogers RO3003 and fed with a microstrip line. The achieved radiation efficiency at 38 GHz is 89.53% and the gain is 6.5 dBi. A patch antenna with the elliptical slotted ground plane designed by (Samsuzzaman, 2020) for both lower (28GHz) and upper (38 GHz) frequency bands. The antenna is structured in Roger's 5880 medium with a dimension of 4.2 x 4.2 x 0.2 mm3. The achieved maximum gain for single unit antenna design for 28 GHz is 3.81 dBi and for 38 GHz frequency is 4.86 dBi. A T and L shape slotted patch antenna with a size of 10 x 10 x 1.6 mm3 for 28GHz frequency designed by (Saini, 2017). The achieved gain for the T shape slot is 6.4 dB and 5.54 dB for the L shape slot antenna design. (Alnemr, 2020) presented a circularly polarized microstrip antenna for fifth generation wireless system applications. The proposed design consists of truncated sides and I shape slots to improve the performance and the design is fed through one side fed strip line. After the simulation the achieved maximum gain individually for 28 GHz and 38 GHz is 5.1 dBi and 5.7 dBi. The obtained efficiency is 88% and 90% for the 28 GHz and 38 GHz bands separately.

By comparing different patch antennas the concerns that arise with the cited work are a larger size, complexity, lower efficiency, and low gain. The focus of this work is to get better performance and reduces the design complications of patch antenna for fifth generation wireless communication. In this work, an elliptical shape slot patch antenna is designed for 28GHz and 38 GHz millimeter wave frequency bands. The manuscript includes four sections; section II describes the design and simulation outcomes of an elliptical patch antenna with a single element. In section III the formulation and analysis of the multilayer patch array antenna presented. Lastly, the work is concluded from the results.

II. Design of Single Element

Fig. 1 presents the structure of an antenna with a single element. The selection of substrate is an important step while designing the antenna. Antenna parameters such as bandwidth and impedance matching are affected by substrate dielectric constant, height, and loss tangent. In this paper, the antenna is created with the Rogers RT/duroid 5880 substrate with a size of 0.25 mm, loss tangent of 0.003, and dielectric constant of 2.2. The antenna design consists of an elliptical slot with coaxial feeding to improve the antenna performance. For the elliptical slot, *a* is the diameter of the major axis and *b* is the diameter of the minor axis. The radius of the round patch is computed by the below expression (Balanis, 2005).

$$R = \frac{F}{\left\{1 + \frac{2h}{\pi \varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + \right]1.7726\right\}^{1/2}} \quad (1)$$

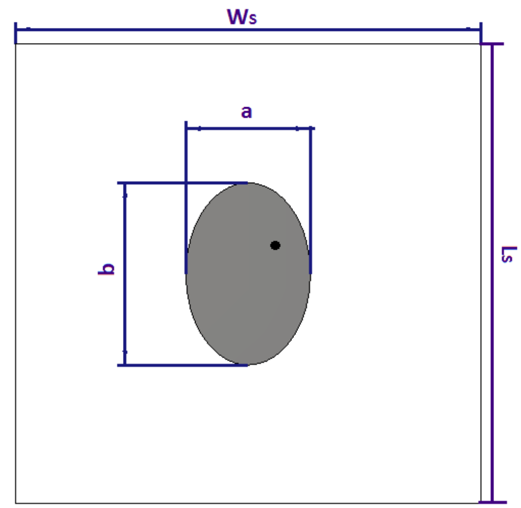


Fig. 1. Structure of the proposed single elliptical patch antenna

Where R is the radius of the elliptical patch, ε_r is the dielectric constant of the substrate, h is substrate height, f is the resonance frequency, and F is given by:

$$F = \frac{8.791\ X\ 10^9}{f_r \sqrt{\epsilon_r}} \quad (2)$$

Table I represents all the specifications of the elliptical patch antenna. The proposed elliptical patch design is sculptured and simulated by the CST Microwave Studio Suite, 2018. Fig. 2 presents a reflection coefficient (S11) graph for a single element antenna covering the 28 GHz and 38 GHz frequency ranges. For the 28 GHz frequency band the obtained S11 is -17.616 dB and for 38 GHz achieved S11 is -14.625 dB. Fig. 3 shows the total efficiency for the dual band single element antenna design. The obtained efficiency at 28 GHz is 76.96% and at 38 GHz is 89.86%.

Table I. Parameters of the proposed design with dimension

Parameters	Dimension (mm)	Description
L_s	10	Substrate length
W_s	10	Substrate width
h	0.25	Substrate height
b	3.96	Major axis diameter (y-direction)
a	2.68	Minor axis diameter (x-direction)
R	2.39	Patch radius

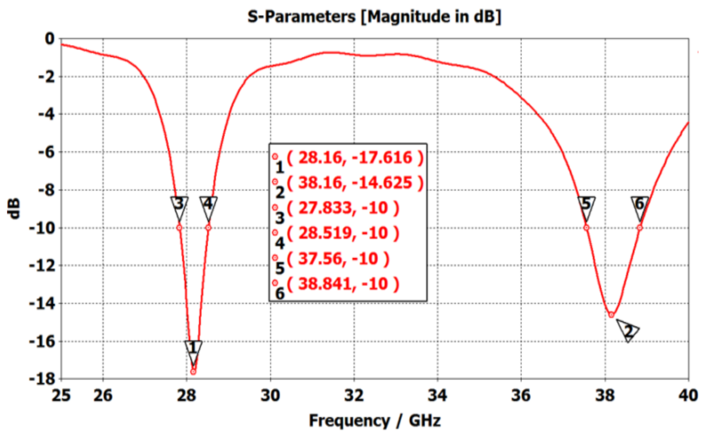


Fig. 2. Return loss (S11) for single patch antenna at 28GHz and 38 GHz

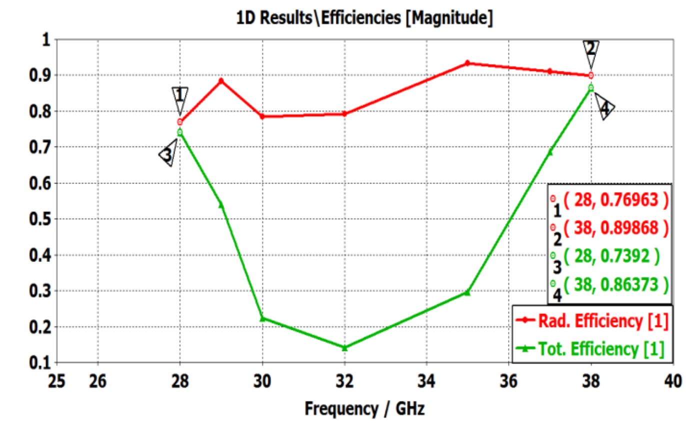
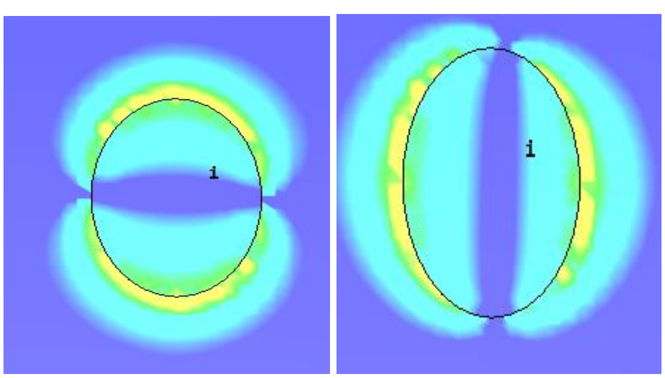


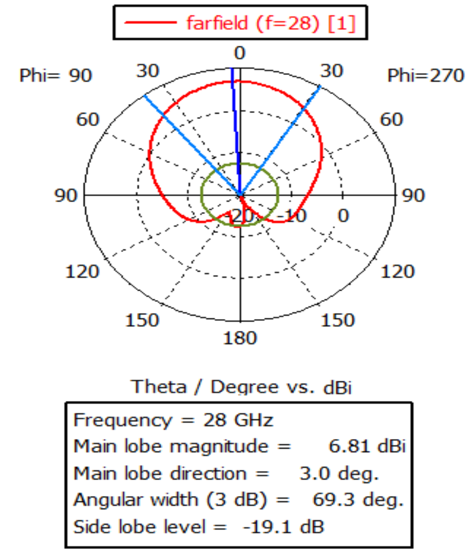
Fig. 3. Efficiency plot for single element design at 28 and 38 GHz

To generate the dual band the proposed antenna is orthogonally polarized with TM_{10} and TM_{01} dominant modes (Mashayak, 2018; wang 2018). Fig. 4 shows the electric field distribution at 28 GHz and 38 GHz for a single patch. To achieve the gain the far field pattern is generated for both frequencies. Fig. 5 shows the maximal gain of the presented antenna with a single component. The achieved gain at the frequency band of 28 GHz and 38 GHz is 6.8 dBi and 7 dBi accordingly.

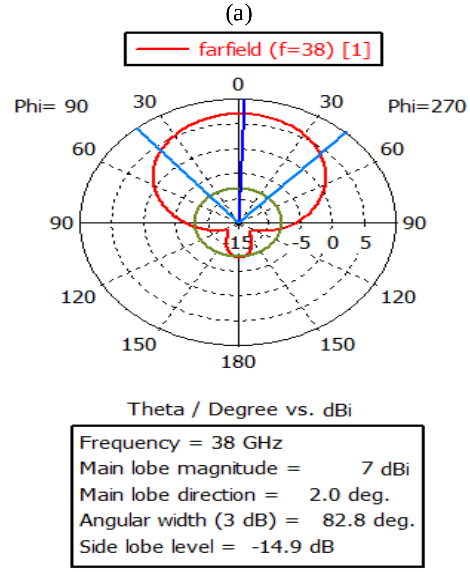


(a) (b)

Fig. 4. E-field distribution at (a) 28 GHz and (b) 38 GHz



(a)



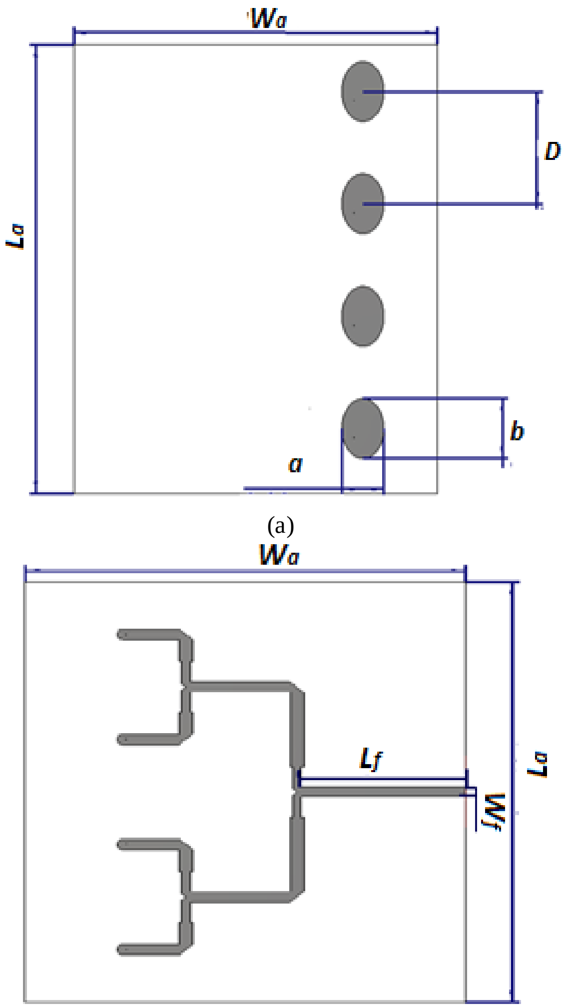
(b)

Fig. 5. Farfield pattern for single element design at (a) 28 GHz and (b) 38 GHz

III. Antenna Array Design and Analysis

In this section, a multilayer antenna array structure is designed to achieve high gain. A four element multilayer elliptical patch antenna array is designed with the coaxial to microstrip line transition and power divider network (Wartenberg, 2004; Morgan, 2002). Antenna arrays are separated by the single ground plane to isolate field patterns. For creating a multilayer structure two substrate layers are created at the top and bottom of the ground plane (Jothilakshmi, 2017).

Fig. 6 depicts a four-element elliptically slotted dual-band multilayer patch antenna array and a corporate feeding network to excite elements of the array. All design parameter values are given in Table II. To excite the elements of the array a corporate feeding network with a two-stage power divider is designed.



(b)

Fig. 6. Geometry for array structure at 28 GHz and 38 GHz frequency (a) 4 element multilayer antenna array and (b) feeding network

Table II. Parameters of the proposed antenna array with dimension

Parameters	Dimension (mm)	Description
L_a	10	Substrate length
W_a	10	Substrate width
D	7.50	Distance between patch
L_f	9.00	Center feed length
W_f	0.75	Center feed width

After Simulation the result parameters for the antenna array such as S11 parameter, efficiency, VSWR, and radiation pattern are generated and analyzed.

A. *S11 Parameters*

While measuring the performance of antenna S11 parameter which is also named return loss plays a significant role. Return loss -10 dB means that thirty percent energy is emitted from the antenna and seventy percent energy is return to the antenna. Fig. 7 represents the plot of return loss for antenna array at lower and higher frequency band.

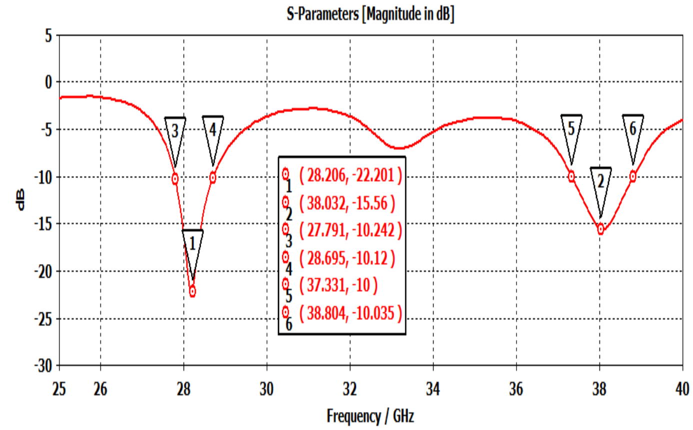


Fig. 7. Return loss (S11) for antenna array at 28 and 38 GHz

From the plot, it is depicted that the S11 (return loss) parameter for the patch array antenna at 28 GHz is -22.201 dB and at 38 GHz the return loss is -15.56 dB. At 28 GHz band (27.79 GHz-28.70 GHz) the achieved bandwidth is 0.723 GHz and for 38 GHz band (37.33 GHz-38.80 GHz) bandwidth is 1.4 GHz.

B. *Efficiency*

The efficiency of the antenna shows that how efficiently power is radiated and receives. It is the relation of radiated power and power given to the antenna. Fig. 8 shows the overall efficiency and radiation efficiency of the patch antenna array at lower (28 GHz) and upper (38 GHz) frequencies. The achieved overall efficiency at 28 GHz and 38 GHz are 80.38% and 79.68% discretely.

C. *VSWR*

VSWR refers to voltage standing wave ratio which is constantly a positive integer. It depicts the reflected power out of the antenna also shows the impedance matching of the antenna and power line. The typical value of VSWR is equal and in the middle of 1 and 2. Fig. 9 shows the VSWR plot for patch array antenna for 5G bands at 28 GHz and 38 GHz. For lower as well as upper frequency the value of VSWR is near 1 which makes the array antenna effective.

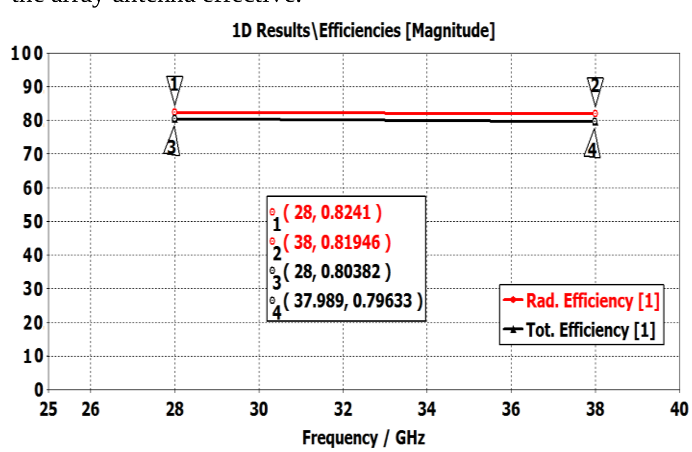


Fig. 8. Efficiency plot for patch array antenna at 28 GHz and 38 GHz

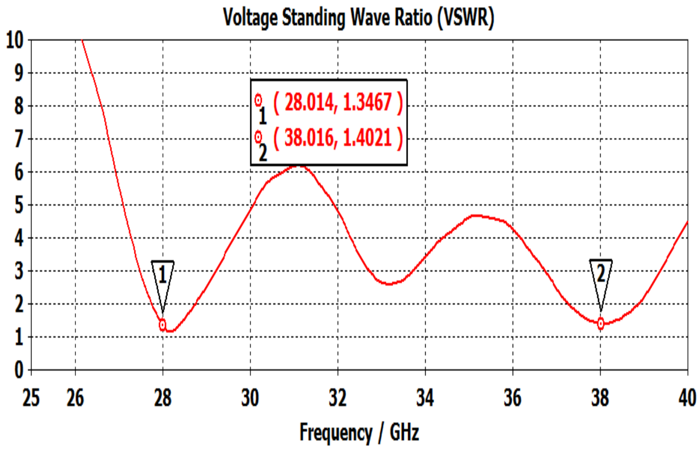
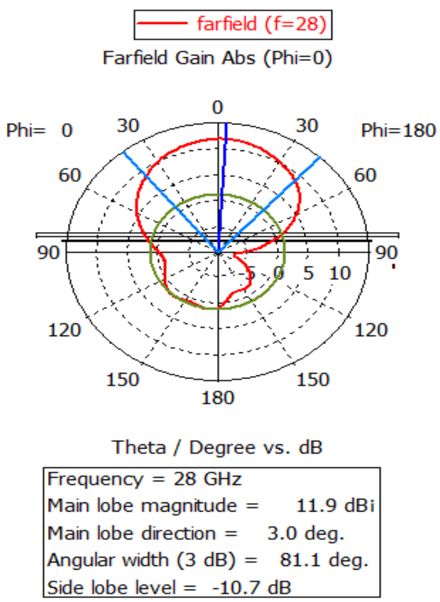


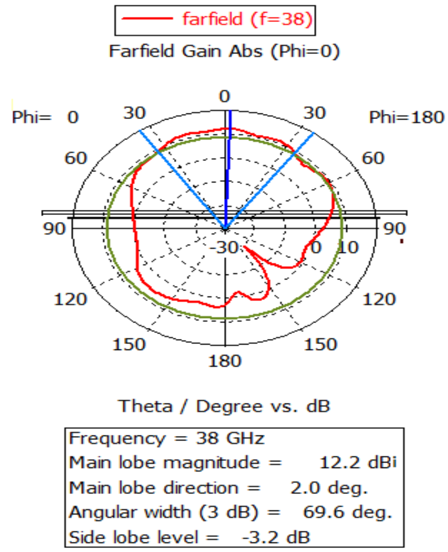
Fig. 9. VSWR plot for patch array antenna at 28 GHz and 38 GHz

D. Far-field pattern

Farfield or radiation pattern is a graphic presentation of an antenna shows that how much energy is radiated by the antenna. The direction properties of the antenna can be realized by an antenna farfied pattern. The polar plot for the radiation pattern is shown below figures for the antenna array. Fig. 10 presented the polar plot for the radiation pattern at 28 and 38 GHz frequency. From the plot, the obtained gain for the antenna array for 28 GHz is 11.9 dBi and for 38 GHz is 12.2 dBi.



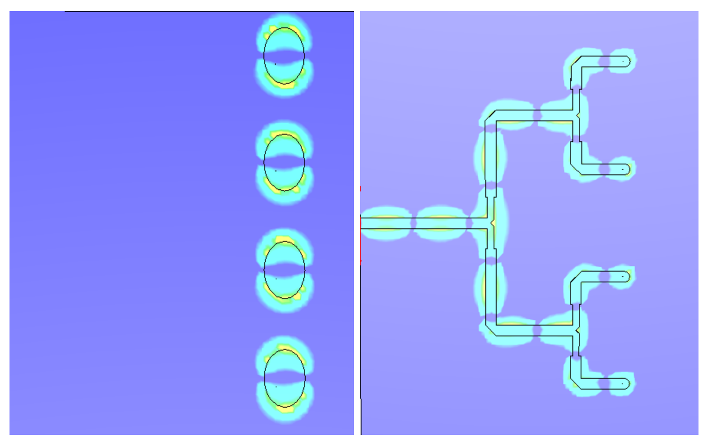
(a)



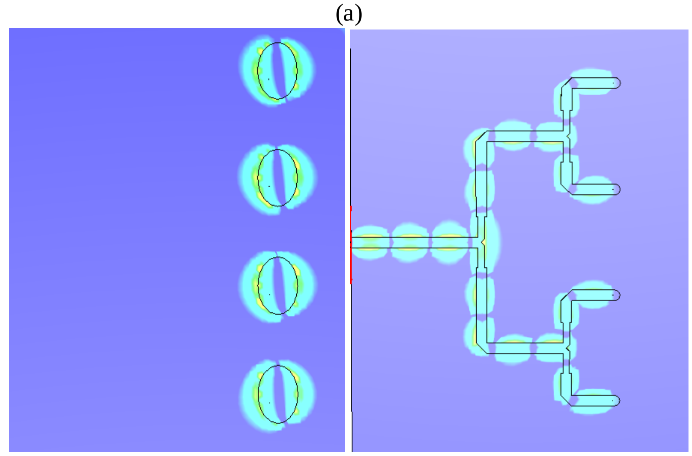
(b)

Fig. 10. Farfield directivity polar plot at (a) 28GHz (b) 38 GHz

Fig. 11 indicates the electric field distribution of the patch antenna array and its feeding network for 28 GHz and 38 GHz frequency. From this E- field distribution we can see that power is equally distributed from the power divider and provides perfect phase matching for all four ports.



(a)



(b)

Fig. 11. Electric field distributions patch array antenna (a) 28 GHz and (b) 38 GHz

After analysing the performance of single patch antenna and patch array antenna is it proved that the antenna array provides improved performance with regard to bandwidth, efficiency, and gain. Table III shows the comparative analysis of different patch antenna.

Table III. Comparative analysis of different patch antenna

Reference	Frequency (GHz)	Gain (dBi)	Efficiency (%)
Ahmad, 2017	28, 38	3.75, 5.06	-
Gunaram, 2020	28	3.76	-
Sharaf, 2020	38	6.5	89.53
Mpele, 2019	28, 38	6.0, 6.3	93.63, 91.08
Samsuzzaman, 2020	28, 38	3.8, 4.8	92,90
Alnemr, 2020	28, 38	5.1, 5.7	88, 90
This work (single element)	28, 38	6.8, 7.0	76.96, 89.86.
This work (antenna array)	28, 38	11.9, 12.2	82.41, 81.94

CONCLUSION

A novel dual-band multilayer elliptical patch single element antenna and antenna array with coaxial to microstrip line transition and feeding network is presented in this paper for 5G applications. The designed antenna is working at frequency bands of 28 GHz and 38 GHz. First, a single element antenna was designed then to improve performance at high frequency the multilayer patch antenna array structure is created. For a single element, the achieved gain for the lower band (28 GHz) and upper band (GHz) is 6.8 dBi and 7.0 dBi individually. For the proposed antenna array design acquired gain for 28 GHz is 11.9 dBi, while for 38 GHz gain is 12.2 dBi. Subsequently surveying the result specifications, it can say that the designed elliptical patch array antenna fulfilled the whole 5G necessity.

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