DESIGN AND ANALYSIS OF MIMO PATCH ANTENNA FOR 5G WIRELESS COMMUNICATION SYSTEMS

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ABSTRACT

In this work, the circular array microstrip patch antenna (MPA) design is proposed for the 5G wireless communication and the millimeter- wave frequency being utilized for this communication system to enhance the coverage area. Here, the Multi Input Multi Output feeding technique is utilized to improve the performance of the proposed design at a resonant frequency of 35 GHz with RT-Duroid 5880 material as substrate. It has 2.2 dielectric constant value and the thickness is 0.5mm.The simulation analysis has obtained the gain as 8.8dB and return loss as -41.9dB. Also, two MPA designs such as single element MPA and 2x2 rectangular array MPA are designed to validate the proposed antenna design. A comparative analysis has proved that the circular array MPA is preferable for the 5G wireless communication system compared to the other two designs such as single element MPA and 2x2 rectangular array MPA.

KEYWORDS

Wireless communication, Bandwidth, Radiation efficiency, Antennas, Microstrip patch antenna (MPA).

1. INTRODUCTION

In this digital communication environment, the evolution of the communication has rapidly developed from telegraphy to wired and after that the radio frequency waves are successfully sent and received that is introduced by G.Marconi in 1901. This evolution is known as wireless communication and still they are developing based on the usage of this communication in normal life [1]. This wireless communication also faced various generations from the analog transmission that is called first generation (1G) to digital transmission based on internet protocol (IP) which is called fourth generation (4G). The current communication is in 4G and the usage of this generation is rapidly increased due to the development of technologies. While usages are increasing, the speed of the 4G data is dropping gradually in the peak hours and it makes the data sharing process very complex for the end user. This event is generating a huge demand for the communication system that requires large number of traffics in future.

Therefore, the digital communication environment is looking forward for the next generation of communication system which is called fifth generation (5G) [2]. The main goal of this generation development is the user endured data should in the speed of 100Mb/s, the area traffic capacity should in 106device/km^2, peak data rate should in 20 Gb/s, latency should in 1ms, and forward compatible for the efficient future evolution [3]. The 5G communication system is not a lone technology rather than it is an ecosystem of the wireless communication. For this 5G

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communication, Millimeter wave is mostly suggested due to its extremely high frequencies and the frequency of above 30GHz to 300GHz [4].

The basic communication system contains transmitter, receiver, and medium. In the communication system, the radio frequencies are transmitted from transmitter to receiver by utilizing the medium. Here, the device which is used to transmit or receiver is called as antenna. Therefore, antenna is playing a significant role for the wireless communication system. Antennas require appropriate design based on their applications to perform efficiently and the performance of the antenna is defined by the parameters [5]. Many parameters exist, for this work most significant parameters used such as gain, return loss, VSWR, bandwidth, Mutual coupling, and radiation pattern [6]. Gain is playing an important role in the antenna parameter which is defined as the strength of sent or received radio frequency signals in a particular direction. Return loss of the antenna is calculated to discover the ratio of the reflected frequencies to the applied frequencies. Therefore, the value of the return loss in an antenna must be less. VSWR (Voltage standing wave ratio) is utilized to calculate the efficiency of the transmitted radio frequency power in antenna. For the good antenna design, the value of the VSWR should be maintained between 1to2. Bandwidth measures the range of frequencies between which the antenna can properly transmit or receive the radio frequencies. The electromagnetic interactions between the elements of antenna are defined as the mutual coupling [7] [8]. This also need to be obtained as much as less for the good antenna. Radiation pattern of the antenna is representing the energy radiated from the antenna [15] [16].

Motivation and objectives

Compared to other feeding techniques, microstrip line feeding is easy for manufacturing and placing over the substrate. Most of the array antennas contain two types of ports such as Single input single output (SISO) and Multi input multi output (MIMO). Still, MIMO is commonly utilized for the wireless communication because it can able to give 120 Mbps data speed which is five times faster than the SISO. It also covers the maximum area and gives better noise power ratio by increasing the range of antenna's frequency. From the above detailed explanation about the antenna communication for 5G, this work is proposing an ovel microstrip patch antenna design with circular array for millimeter wave wireless communication. Here, the performance of the antenna is enhanced by utilizing MIMO for the substrate material, RT-Duroid 5880 used. The proposed antenna design is compared with two other designs such as single element and 2x2 rectangular array patch antenna for evaluating its performance.

2. LITERATURE SURVEY

In this section, some recent literatures which focused research on design of microstrip patch antenna are reviewed. Nam Kim et al [9] had presented the design and realization of low-profile wideband Circularly Polarized (CP) patch antenna based on metasurface for 5G communication framework. In the approach, between the ground plane and an array of 4 × 4 symmetrical square ring Metasurface a modified patch was sandwiched. The proposed scheme achieved wide bandwidth from 24 to 34.1 GHz. R. Ahila Priyadharshini et al [10] had proposed half-mode substrate integrated waveguide abbreviated as HMSIW and double band substrate integrated waveguide abbreviated as SIW. The authors had received an aggregate of two SIW cavities of different dimensions via coupling window by the proposed antenna. Because of the proposed scheme, the authors had improved the radiation efficiency and gain performance. Duy Hai Nguyen et al [11] had proposed a single polarization, 4×4 microstrip patch antenna array, performing at Ka–band. The array of antenna was performed by an integrated microstrip network utilizing feeding probes. This proposed approach achieved high suppression of sidelobe and cross-polarization. Kuo-Sheng Chin et al [12] had proposed a wide-beam microstrip patch antenna as well as antenna array ranging from 77 to 81 GHz. Two I-shaped parasitic elements were positioned near to the major patch for establishing a three-element subarray. Results of the article showed that the proposed design achieved 10.74 dBi gain and wide beamwidth of 138^0 at 79 GHz. Ayman Ayd R. Saad, Hesham A. Mohamed [13] had presented a broadband mm-wave MIMO antenna framework for 5G networks. The radiation characteristics were improved by integrating the EBG reflector into the antenna system. The proposed antenna design achieved high isolation ranging from 22.5 to beyond 50 GHz. Ahmed Abdelaziz and Ehab K. I. Hamad [14] had presented a slotted complementary split-ring resonator and the theory of characteristic modes based a compact 5G MIMO microstrip antenna with isolation improvement. The filtering characteristics of the band-gap structure were illustrated by introducing the dispersion diagram analysis. Form the implementation results, the authors confirmed that the element of proposed antenna was isolated with −54 dB at 28 GHz.

3. DESIGN PARAMETERS OF PROPOSED MPA

The basic microstrip patch antenna has patch, substrate, ground plane and feed line and these portion's geometrical designs are calculated by utilizing the Maxwell equation. These equations are introduced by Maxwell who combined the theory of magnetism and electricity. For the design, RT-Duroid 5880 material is used as substrate which has the dielectric constant value ε_r as 2.2 and the thickness of the substrate h is 0.5mm. Every antenna requires the resonance frequency for the process and the proposed work is utilizing 35GHz as the resonance frequency which is more preferable for the 5G wireless communication. The design parameters of the patch antenna are evaluated by utilizing following equations.

The width of the patch is calculated by utilizing the equation,

$$W_p = \frac{c}{2f_r\sqrt{\frac{(\varepsilon_r+1)}{2}}} \tag{1}$$

Here, W_p is representing the patchwidth, c is representing the speed of light which has value 3×10^8, the resonance frequency is denoted as f_r, and ε_r is representing the dielectric constant value.

The length of the patch is given by,

$$L_p = L_{peff} - 2\Delta L_p \tag{2}$$

Where, the effective length of the patch is denoted as L_{peff} and ΔL_p representing the extension length of patch. The extension of patch length is formed due to the electrical distribution over the antenna. The effective patch length L_{peff} and the extension of the patch length ΔL_p are derived by applying the following equations,

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

$$\Delta L_p = 0.412h\frac{(\varepsilon_{reff}+0.3)\left(\frac{W_p}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W_p}{h}+0.8\right)} \tag{4}$$

Where, h is representing substrate thickness, effective dielectric constant is denoted as ε_{reff} and it is calculated by utilizing the below equation,

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 12\frac{h}{W_p}\right]^{-1/2} \quad (5)$$

The length of the substrate is estimated by the following equation,

$$L_g = 6h + L_p \quad (6)$$

Where, the length of the substrate is denoted as L_g.

Substrate's width is given by,

$$W_g = 6h + W_p \quad (7)$$

Where, the width of the substrate is represented by W_g.Here, the length and width of the ground plane is also considered same as that of substrate length and width to progress the performance. The length of the microstrip feed line,

$$L_f = \frac{1}{4}\lambda_g \quad (8)$$

Where, the length of the microstrip feed line is represented as L_f, guided wave length is denoted as λ_g and it is estimated by implementing the below equation,

$$\lambda_g = \frac{\lambda}{\sqrt{\varepsilon_{reff}}} \quad (9)$$

Here, λ is denoted as the wavelength and it is derived by the below given equation,

$$\lambda = \frac{c}{f_r} \quad (10)$$

The feed line width,

$$W_f = \frac{7.48\times h}{e^{\left(Z_0\frac{\sqrt{\varepsilon_r+1.41}}{87}\right)}} - 1.25\times t \quad (11)$$

Where, W_f is representing the width of the feed line, Z_0 is representing the impedance value, and t is representing the trace thickness.

For this design, Z_0 is taken as 50Ω and trace thickness is taken as 0.0175mm which is the standard trace thickness for the microstrip patch antenna. With the help of the above equations, the designing parameters are calculated and the values which are obtained in the calculation that is optimized to enhance the performance of the patch antenna. The obtained designing parameters are depicted in the table1.

Table1. Obtained and optimized values of design parameters

Design parameters	Description	Obtained values from calculation (mm)	Optimized values for performance(mm)
W_p	Width of patch	3.386	3.62
L_p	Length of patch	2.551	2.45
W_g	Width of substrate and ground plane	5.49	6
L_g	Length of substrate and ground plane	4.65	6
W_f	Width of feed line	0.46	0.46
L_f	Length of feed line	1.57	1.57

The above-mentioned optimized values (table1) are applied for the microstrip patch antenna design to attain efficient results. The utilization of these parameters for the design of proposed microstrip patch antenna is described clearly in the following sections.

4. DESIGN AND ANALYSIS OF MPA

The design and analysis for the three types of microstrip patch antenna (MPA) such as Single element MPA, 2x2 rectangular array based MPA, and circular array based MPA are described in this section. The circular array based MPA can be used for 5G wireless communication. The whole design analysis process is conducted in High-Frequency Structure Simulation (HFSS) which is the platform of ANSYS software. The designed antennas are validated by attaining the parameters such as Gain, Return loss, Mutual coupling, VSWR, and Bandwidth. The parameter values of three MPA designs are compared to find the efficient antenna for the 5G wireless communication. The copper material with 0.0175mm is utilized for the patch and ground plane. The resonance frequency for these three-antenna designs is taken as 35GHz which is best for the 5G wireless communication.

4.1. Design of single element MPA

In this section, single element MPA is designed and validated by attaining the validation parameters such as Gain, return loss, mutual coupling, VSWR, and bandwidth. Single element antenna contains single patch and single feed line which are utilized as the transmitter or receiver. The antenna geometry is utilizing the optimized parameters for the single element MPA design. The figure1 shows the 2D design for the designed single element MPA an d figure2 shows the 3D design for the single element MPA.

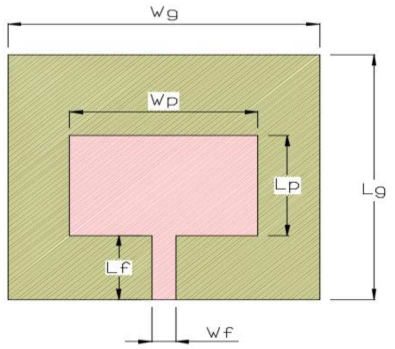


Fig.1 2D design of single element MPA

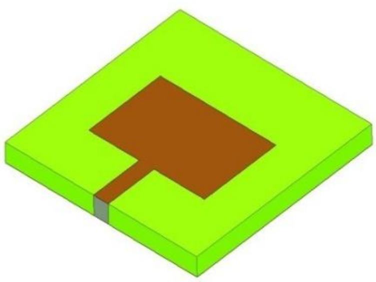


Fig.2 3D design of single element MPA

At first, the substrate is designed in the HFSS by utilizing the optimized design parameters and the property of the substrate is selected in the solids which are presented in the HFSS. Then the patch and feed line are designed as per the optimized parameters over the one side of the substrate and the other side is covered by the ground plane. Then port design is in appropriate location. Finally, the radiation box is designed with 15mm length, 15mmwidth, and 8mm height which are randomly selected. After the completion of design portion, the boundaries are assigned for the analysis process. Patch, feed line and ground plane are assigned as perfect E and the radiation box is assigned for the radiation boundary. The port is assigned as the lumped port excitations and the full port impedance value is set as 50Ω. Finally, the analysis setup is proceeded for the simulation process and this setup is called as sweep. Here, the frequency is set to 35GHz and the maximum number of passes is set as 20.

4.2. Design of 2x2 rectangular array

In this section, the structure of 2x2 rectangular array design for the microstrip patch antenna is designed and analysed. The design parameters are similar as the single element MPA, but it has four patches, four ports and four feed lines. Here, MIMO design structure is implemented for this 2x2 rectangular array design. These patches and feed lines are located in 2x2 rectangular array formation over the substrate. Due to the increase in number of patches, the substrate length and width is increased from 6mm to 12mm respectively. Similarly, the ground plane length and width also changed from 6mm to 12mm respectively. The radiation box is designed with 20mm length, 20mm width, and 10mm height. Here, two patches placed in nearby with 0° of rotation and the other two patches are placed on top side of the located patches with the rotation of 90° as shown in figure3. In figure 4, the 3D view of the designed 2x2 rectangular array MPA.

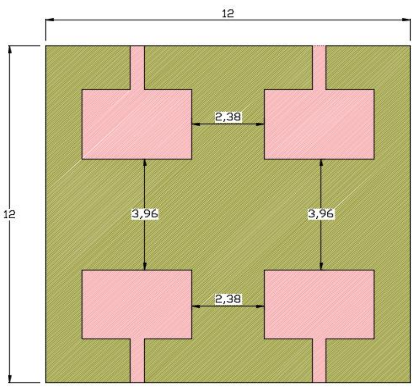


Fig.3 2D design for the 2x2 rectangular MPA array

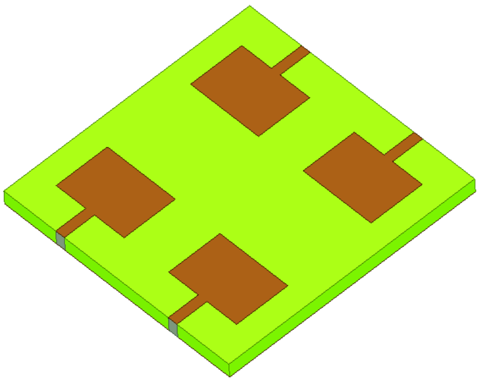


Fig.4. 3D design for the 2x2 rectangular MPA array

Here, the design and analysis setup steps are similar to the single element MPA instead of the array steps. When designing the 2x2 rectangular array, the patches and feed lines are placed over the substrate as shown in figure 4.

4.3. Design of circular array MPA

This section describes the details about designing methods for the proposed circular array MPA. Here, also the same design parameters are used which are already utilized for the single element MPA and 2x2 rectangular array MPA. It also has four patches, four feed lines, and four ports. The dimensions of the substrate and the ground is remaining similar as 2x2 rectangular array. The radiation box of the circular array MPA design is same as 2x2 rectangular array MPA. The patches are located as shown in figure 5 and the 3D view of the proposed circular array MPA is shown in figure 6.

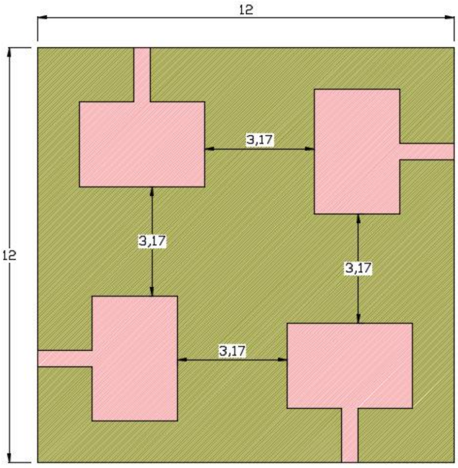


Fig.5. 2D design for the novel circular array MPA

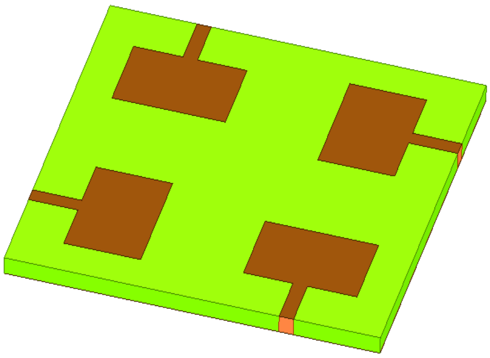


Fig.6. 3D design for the novel circular array MPA

The design of circular array structure is located over the substrate as shown in figure 5. The steps similar to the 2x2 rectangular array MPA. The MIMO design structure is implemented and each patch is located in various angles of rotations such as 0°, 90°, 180°, and 270°. Analysis setups are done as per the single element and 2x2 rectangular array MPA setups. The impedance value of each port is taken as 50Ω and the simulation is run for the analysis.

5. Results and Discussion

5.1. Performance analysis of single element MPA

In sweep setup, the distribution of the frequency is set as linear count and the start and end of the frequency range is set between 28GHz to 42GHz. At last, the single element MPA design is analysed by running the simulation. The obtained results are showed in the table 2.

Table 2. The obtained results from the analysis of single element MPA

Resonance frequency (GHz)	Gain (dB)	Return loss (dB)	VSWR	Bandwidth (GHz)	Radiation efficiency (abs)
35	8.1	-34.5	1.18	1.9(35.7–33.8GHz)	1.02

From the table2, the obtained gain value for the single element MPA is 8.1dB, the return loss for the single element MPA is obtained as -34.5dB, the VSWR value is 1.18, and the Bandwidth of the single element MPA obtained is 1.9GHz (35.7–33.8GHz). The radiation efficiency is obtained in 1.02abs. Return loss graph is shown in figure 7. As shown in the figure single element MPA attained -10dB return loss and 35GHz bandwidth.

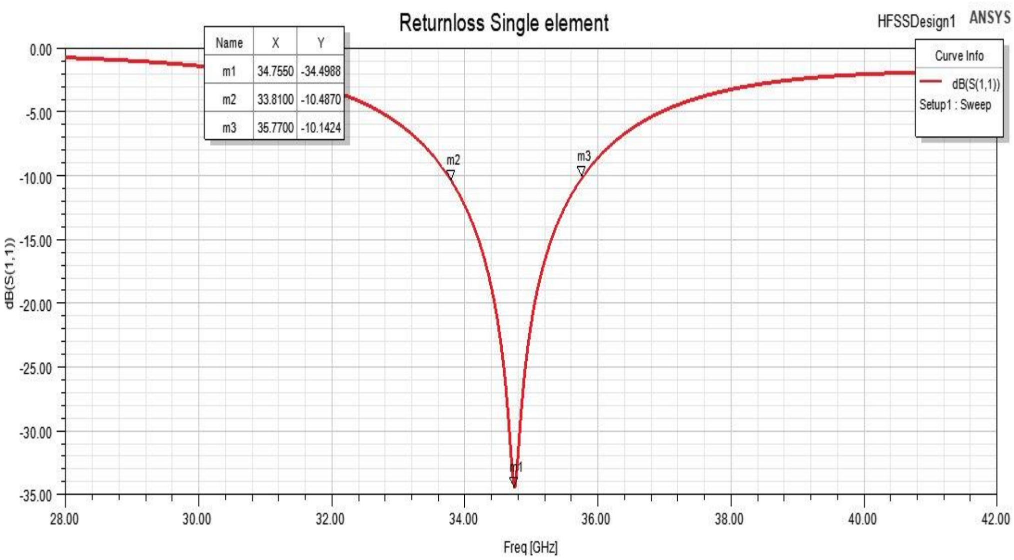


Fig 7. The rectangular plot for the Return Loss of the single element MPA

The VSWR graph for the single element MPA is shown in figure 8. As shown in the figure single element MPA attains 1.18dB VSWR.

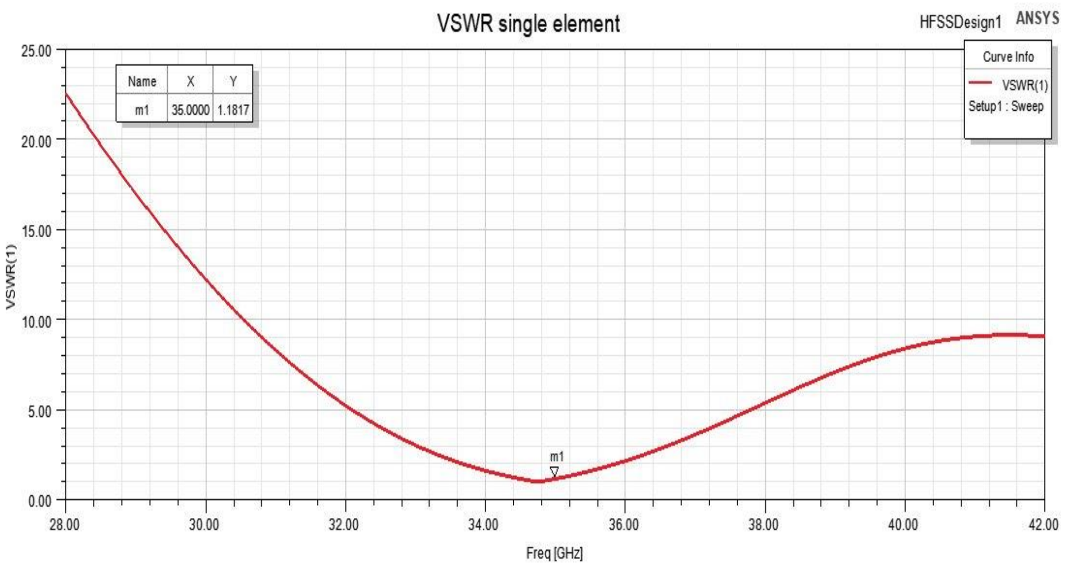
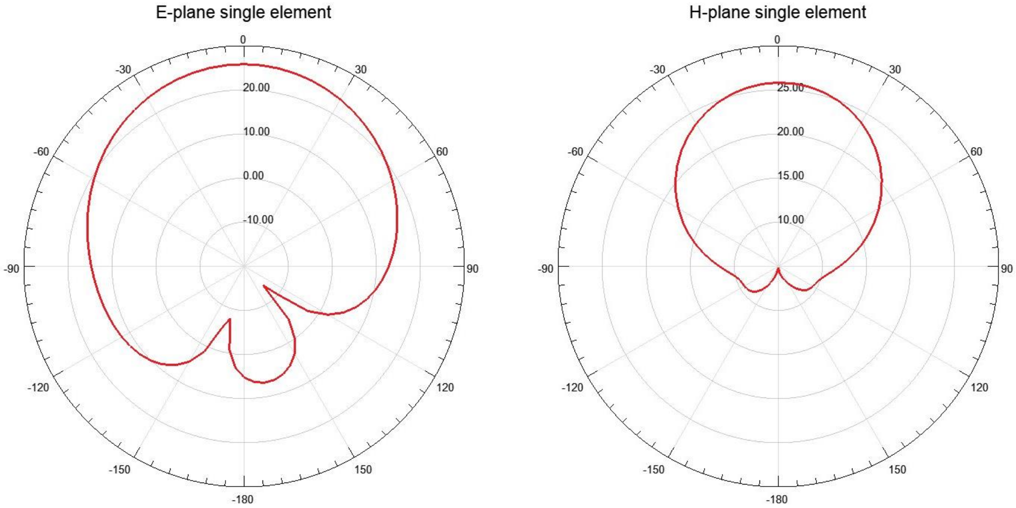


Fig 8. The rectangular plot for the VSWR of the single element MPA



(a) (b)

Fig 9. Radiation pattern for the single element MPA, (a) E-plane, (b) H-plane.

The radiation pattern is shown in figure 9. As shown in the radiation pattern of the E-plane is plotted by setting the theta value in all and the phi value in 0° and for the H-plane, the theta value remains same and the phi value is changed to 90°.

5.2. Performance analysis of 2x2 rectangular array MPA

The analysis and sweep settings are setup same as single element MPA and each port of the patch has the same impedance value which was taken for single element MPA. Finally, the simulation is run for obtaining the results and the obtained results are tabulated in table 3

Table 3. The obtained results from the analysis of 2x2 rectangular array MPA

Resonance frequency (GHz)	Gain (dB)	Return loss (dB)	VSWR	Bandwidth (GHz)	Mutual coupling (dB)	Radiation efficiency (abs)
35	8.4	-33.9	1.6	1.9(35.3–33.4GHz)	-23.05	1.02

From the table 3, the gain for the 2x2 rectangular array MPA is obtained as 8.4dB, the return loss is obtained as -33.9dB, the bandwidth is attained as 1.9GHz (35.3–33.4GHz), the VSWR for this array obtained is 1.6 and the mutual coupling attained is -23.05dB. The radiation efficiency of the designed 2x2 rectangular MPA array 1.02. The obtained return loss is plotted in figure 10. As shown in the figure, the 2x2 rectangular array MPA obtains -33.9dB return loss.

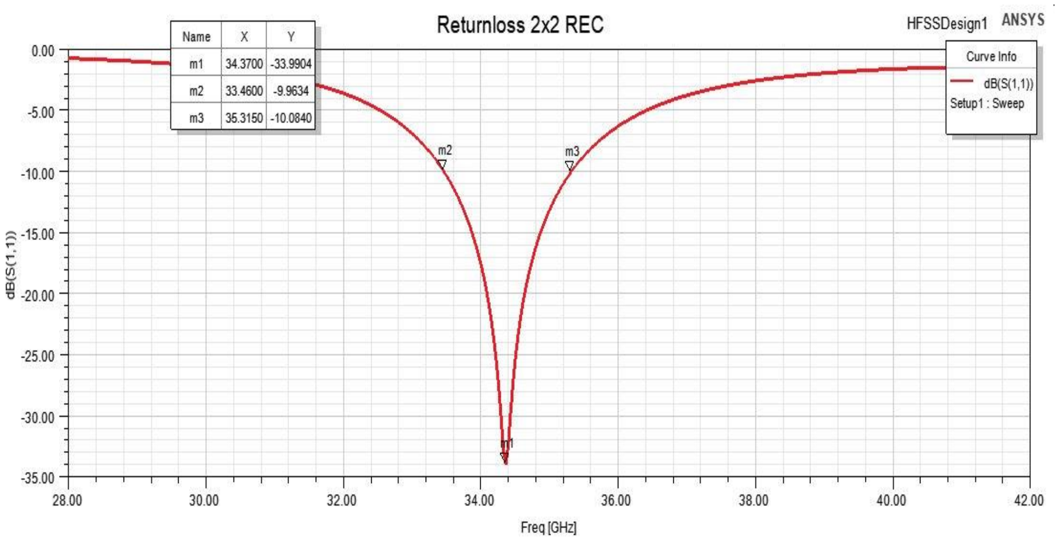


Fig 10. The rectangular plot for the Return Loss of the 2x2 rectangular array MPA

The VSWR, mutual coupling, and radiation pattern for the 2x2 rectangular array MPA are shown in Figures11,12 and 13 respectively. As shown in figure 11, the 2x2 rectangular array MPA attains 1.6dB VSWR. As shown in figure 12, 2x2 rectangular array MPA obtains -23dB mutual coupling.

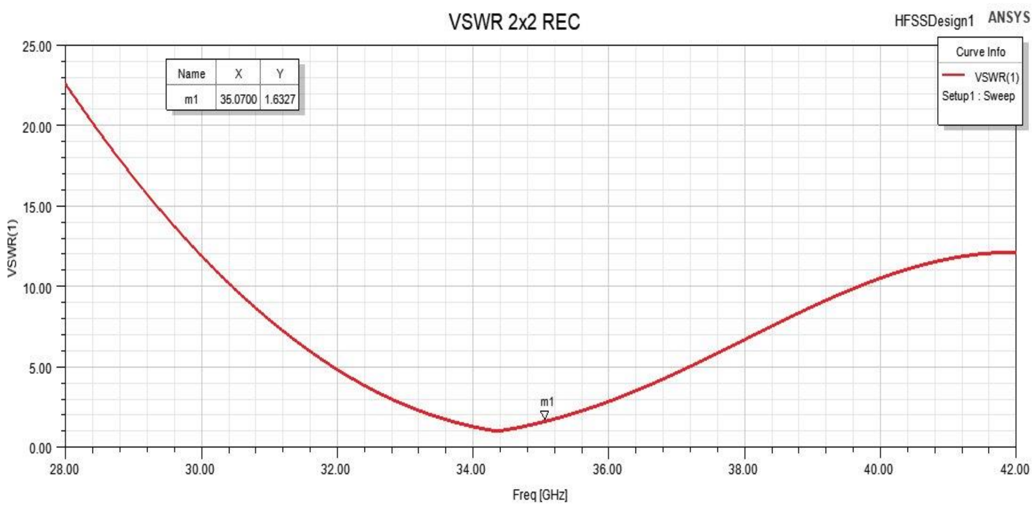


Fig 11. The rectangular plot for the VSWR of the 2x2 rectangular array MPA

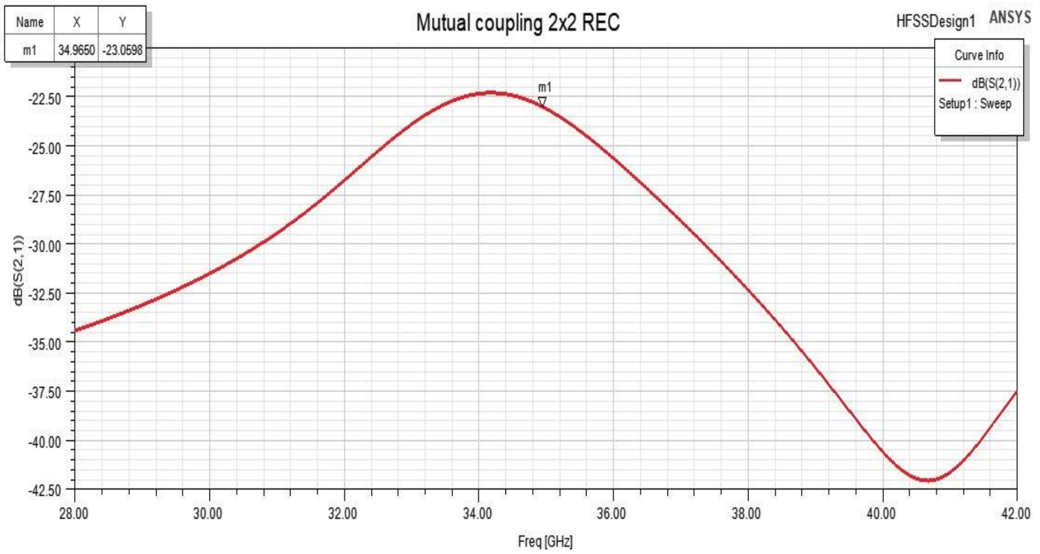
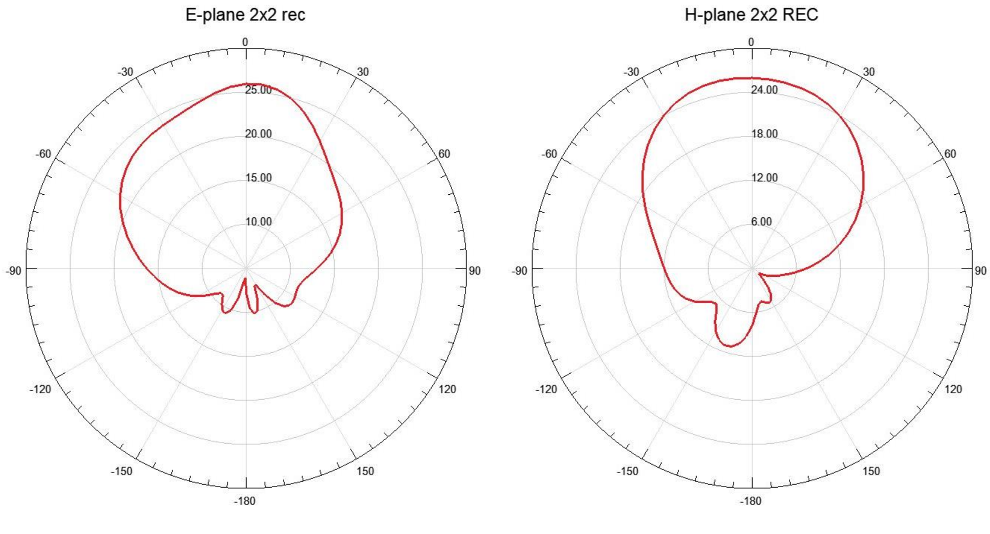


Fig 12. The rectangular plot for the Mutual coupling of the 2x2 rectangular array MPA



(a) (b)

Fig 13. Radiation pattern for the 2x2 rectangular array MPA, (a)E-plane, (b)H-plane.

Where the steps utilized for attaining the radiation pattern of single element MPA are also utilized for attaining the radiation pattern of 2x2 rectangular array MPA.

5.3. Performance analysis of the proposed circular array MPA

The obtained values are tabulated in table 4.

Table 4. The results of the proposed circular array MPA

Resonance frequency (GHz)	Gain (dB)	Return loss (dB)	VSWR	Bandwidth (GHz)	Mutual coupling (dB)	Radiation efficiency (abs)
35	8.8	-41.9	1.19	2(35.7–33.7GHz)	-26.82	1.02

From the table4, the gain obtained for the circular array MPA is 8.8dB, the return loss for this array structure is obtained as -41.9dB, The VSWR is maintained as 1.19, the mutual coupling for this array structure obtained is -26.82 and the bandwidth is obtained as 2GHz (35.7–33.7GHz). The radiation efficiency also obtained in 1.02abs. The return loss is shown in figure14. As shown in the figure, the proposed circular array MPA attains -41.dB return loss.

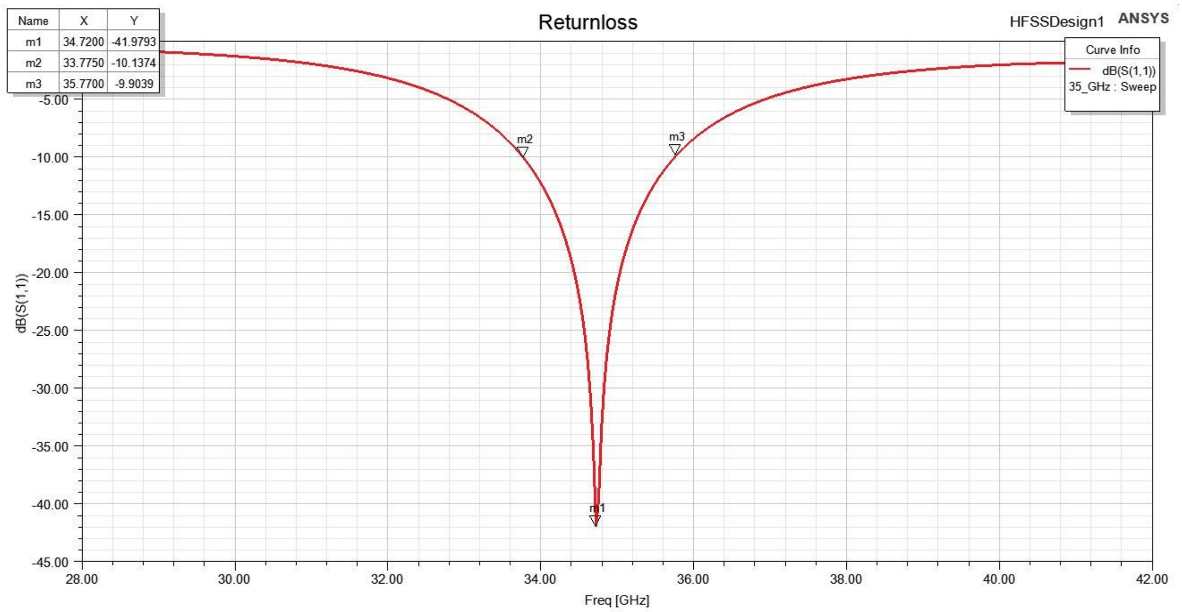


Fig14. The rectangular plot for the Return Loss of the proposed circular array MPA

In figure15, the VSWR rectangular plot for the circular array MPA is shown. As shown in the figure, the proposed circular array MPA achieves 1.19dB VSWR. The Mutual coupling plot is shown in figure16. As depicted in the figure, the proposed circular array MPA obtains -26dB of mutual coupling. The radiation pattern for the circular array MPA is shown in figure 17.

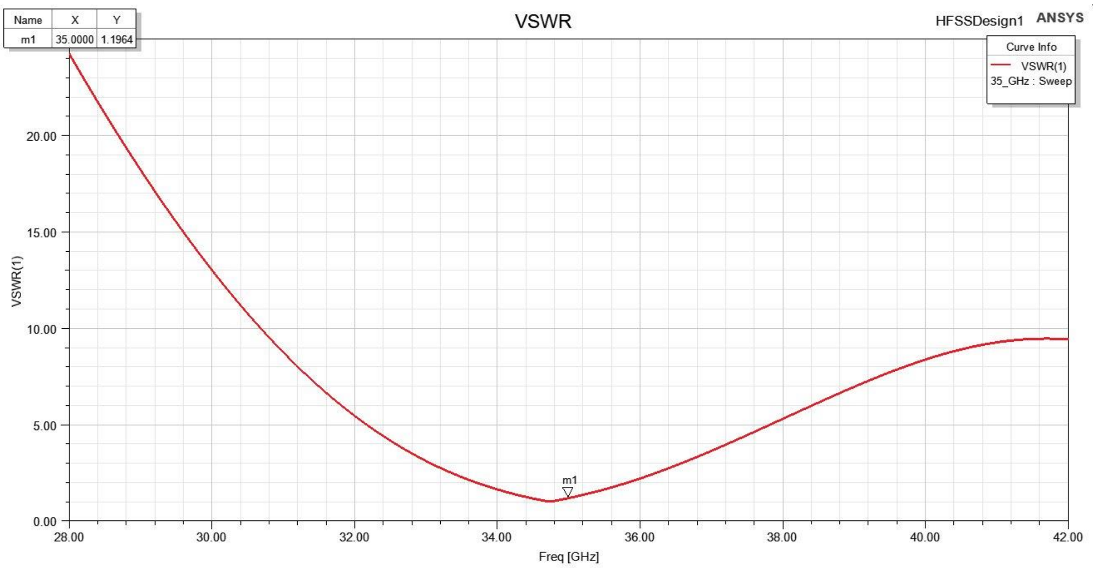


Fig15. The rectangular plot for the VSWR of the circular array MPA.

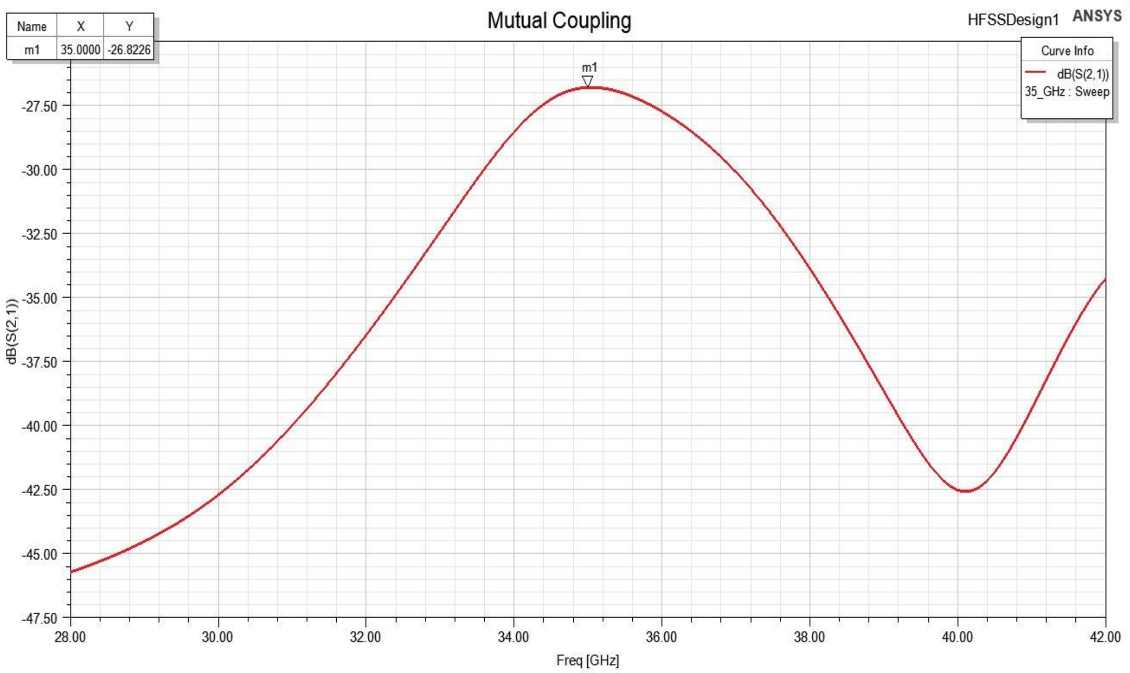
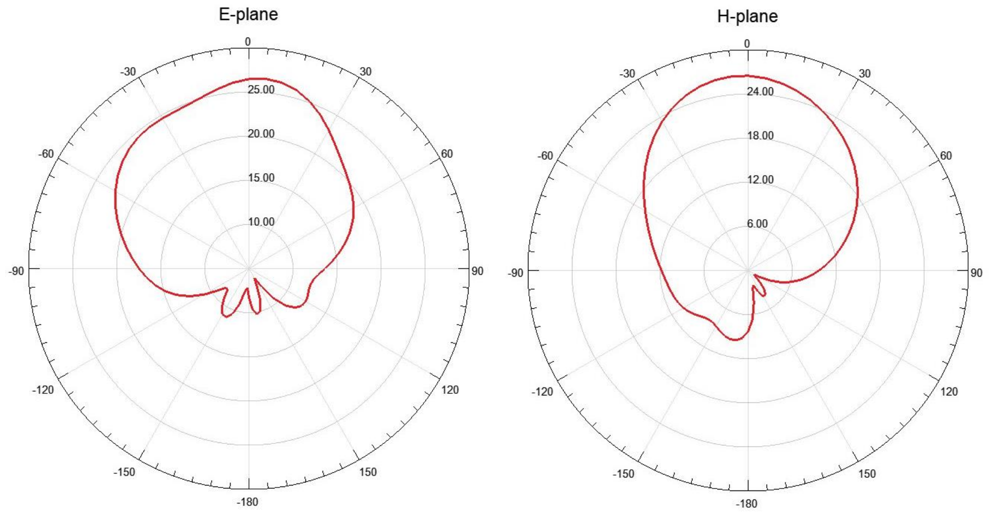


Fig16. The rectangular plot for the Mutual coupling of the circular array MPA.



(a) (b)

Fig 17. Radiation pattern for the circular array MPA, (a)E-plane, (b)H-plane.

5.4. Comparative Analysis

In this section, the comparative analysis is performed between three MPA design such as single element MPA, 2x2 rectangular array MPA, and proposed circular array MPA. Here, the parameters such as Gain, return loss, VSWR, mutual coupling, bandwidth, and radiation efficiency of three MPA are compared. For all three MPA design, 35GHz frequency is utilized as the resonance frequency. Table5 depicts the comparation of the antenna parameters for three different antenna structures. The circular array MPA performs efficiently in Gain compared to the other designs and also has the lowest return loss. The VSWR attained is 1.19 and it is in between the acceptable values of 1and 2. From the table 5 it is also seen that the circular array MPA has higher bandwidth (2GHz) compared to the other two MPA designs. The single element MPA is not considered for mutual coupling because the array designs are only having this. The Circular array MPA has lowest mutual coupling when compared with 2x2 rectangular array MPA. All the three MPA designs have the same radiation efficiency with the value of 1.02abs. From the comparative analysis of the parameters such as Gain, return loss, VSWR, bandwidth, mutual coupling and radiation efficiency, the circular array MPA is performing efficiently in overall when compared to the other two designs such as single element MPA and 2x2 rectangular array MPA. Therefore, the proposed circular array MPA is more suitable and efficient MPA design for the 5Gwireless communication.

Table 5. The comparative analysis of three type of MPA

	Gain (dB)	**Return loss (dB)**	**VSWR**	**BW (GHz)**	**Mutual coupling (dB)**	**Radiation efficiency (abs)**
Single element MPA	8.1	-34.5	1.18	1.9	_	1.02
2X2 Rectangular array MPA	8.4	-33.9	1.6	1.9	-23.05	1.02
Circular array MPA	8.8	-41.9	1.19	2	-26.82	1.02

6. CONCLUSION

The main motivation here is to provide an efficient microstrip patch antenna design for 5G wireless communication. The implementation process is performed on the HFSS which is the platform of ANSYS software. At first, the three MPA designs such as single element MPA, 2x2 rectangular array MPA, and proposed circular array MPA are drafted in HFSS software as per the appropriate optimized parameters. After completing the design section, the simulation is run for the analysis of these three MPA designs. The obtained results are compared to analyse the performance of these three MPA design to discover the best antenna design for 5G wireless communication. From the comparative analysis, the proposed circular array microstrip patch antenna design is efficiently performed in all parameters such as gain, S_{11}, VSWR, mutual coupling, bandwidth, and radiation efficiency. Therefore, the proposed circular array MPA is most preferable for 5G wireless communication. In future, we plan to present a meta-heuristic algorithm for designing the microstrip patch antenna.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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