

# Design and Analysis of High Gain 2x1 and 4x1 Circular Patch Antenna Arrays for 2.4 GHz Applications

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**ABSTRACT:** Microstrip patch antennas are the most useful antennas for the present trend of applications in communications. The well known advantageous mechanical characteristics (low profile, light weight, planar but conformal to non-planar structures, easy to fabricate), flexibility in terms of electromagnetic parameters (radiation pattern, gain, impedance, polarization) and low cost are the key features of the success of such antennas. To meet the requirements of aircraft, spacecraft, satellite and missile applications where size, weight, cost, performance, ease of installation, low profile and easy integration to circuits, high efficiency antennas are required. Microstrip antenna arrays are most suitable for such applications. In this paper various circular patch antenna arrays are designed for the application of WLAN (wireless local area network) at 2.4GHz. Single patch antenna is designed using probe feeding technique. Arrays of 2x1 and 4x1 are also designed using edge feeding technique. The antenna arrays are designed and simulated on FR4 substrate and excited using probe and edge feeding techniques. The antenna arrays are simulated using the High Frequency Structure Simulator (HFSS) software version v17.2 and the parameters like gain, return loss, radiation pattern and VSWR are evaluated at that frequency.

**KEYWORDS:** Microstrip Patch Antenna, FR-4 Substrate, Edge feed and probe feed technique.

## I. INTRODUCTION

Antennas play a vital role in the field of wireless communications. Some of them are parabolic reflectors, slot antennas, patch antennas, and folded dipole antennas. Each one of the antenna is superior in its own characteristics, design and applications. We can state antennas are the backbone and almost everything in the wireless communication without which the world could not have imagined the present day of technology. Patch antennas play a very important role in today's world of wireless communication systems. A Microstrip patch antenna is very simple in the construction using a conventional Microstrip fabrication technique. The patch can take any convenient shape but circular and rectangular configurations are the most frequently used configurations. These patch antennas are used as simple for wide range of most challenging applications. Dual characteristics, circular polarizations, dual frequency operation, frequency agility, broad band width, feed line flexibility and beam scanning can be obtained easily from these patch antennas. [1 - 7]. A Microstrip antenna consists of conducting patch on a ground plane separated by dielectric substrate. We used the dielectric constant substrate FR4 [1 - 6] (FR stands for flame retardant and 4 indicates the type of glass epoxy with  $\epsilon_r = 4.4$ ) for maximum radiation. FR4 is chosen since it is easily available and also relatively cheap in the market.

## II. MICROSTRIP ANTENNA ARRAY

Microstrip antennas are very flexible and are used, along with other things, to synthesize a desired pattern which cannot be obtained with a single element. Also, they are used to scan the radiation pattern beam of an antenna system, enhance the directivity, and execute various other functions which would be complex with single element. The elements can be

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fed by a single line or by multiple lines in a feed network arrangement. So in this paper we used an array to extend the performance of this antenna.

One of the important parameters for the design of a Microstrip patch antenna is the Frequency of operation ( $f_r$ ). The resonant frequency of the antenna should be chosen appropriately. The Industrial, Scientific and Medical (ISM) Systems uses the frequency range from 2.4GHz - 2.5GHz. Hence the designed antenna must be competent to function in this frequency range. The resonant frequency chosen for our design is 2.4 GHz [1].

In our work, firstly we selected the value of the substrate (FR4) [2] parameters relative Dielectric constant ( $\epsilon_r$ ) to be 4.4 and the substrate thickness (h) to be 1.66 mm. Then, we evaluated the radius of the circular Patch using the formula [2 - 3]:

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

$$\text{Where } F = \frac{8.791 \times 10^9}{f_r \sqrt{\epsilon}}$$

We have chosen the inter-element spacing for the 2x1 and 4x1 Antenna arrays to be 62.5 mm.

We also calculated the widths of each of these feedlines which are dependent on their impedance values for 2x1 and 4x1 Antenna arrays using the formula:

$$Z_c = \begin{cases} \frac{60}{\sqrt{\epsilon_{\text{reff}}}} \ln \left[ \frac{8h}{w_0} + \frac{w_0}{4h} \right], & \frac{w_0}{h} \leq 1 \\ \frac{120\pi}{\sqrt{\epsilon_{\text{reff}} \left[ \frac{w_0}{h} + 1.393 + 0.667 \ln \left( \frac{w_0}{h} + 1.444 \right) \right]}}, & \frac{w_0}{h} > 1 \end{cases}$$

Further, we also evaluated the Return loss, Gain, VSWR, Impedance Bandwidth, 3 dB Beamwidth for single Circular Patch Antenna. Then we extended the work to evaluate the above mentioned parameters to 2x1 and 4x1 array by using the High Frequency Structure Simulator (HFSS) software version v17.2.

## III. DESIGN OF CIRCULAR MICROSTRIP PATCH ANTENNA ARRAYS

### 3.1 Configuration of Single Circular Patch Antenna:

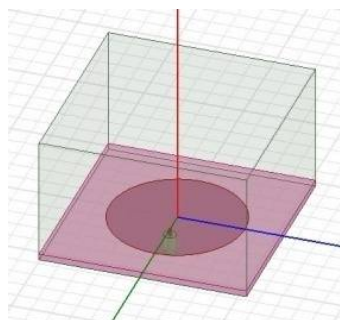


Fig. 1. Configuration of single patch

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For a single circular patch optimal feed location is usually at one third distance from centre of the patch. The feed location is calculated using the formula:

$$y_f = \frac{W}{2} \text{ and } x_f = \frac{L}{2\sqrt{\epsilon_{r,eff}.L}}$$

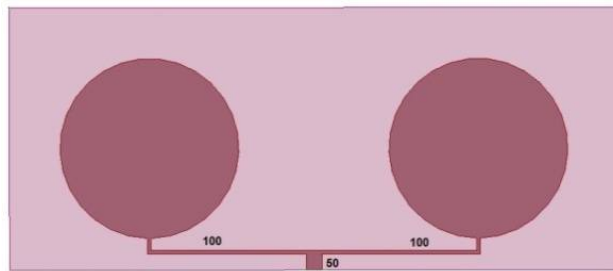
The feed location is further optimized for better results by optimizing the feed location along x-axis or y-axis or both. The calculated dimensions are tabulated in the table 1:

Radius of the Patch	17 mm
Feed location	(5.5,0)

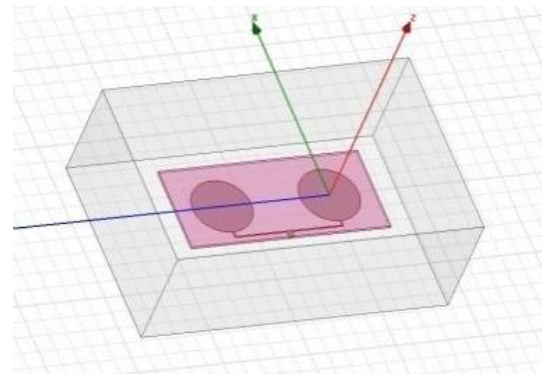
Table 1: Dimension of single patch

### 3.2 Design Analysis for 2x1 Antenna Array [4 - 5]:

We used the same values of height of the dielectric substrate (h) and the same dielectric material (FR4) at the design frequency.



(a)



(b)

Fig. 2. 2x1 patch antenna array (a) Configuration (b) Design

Each of the patch is connected to 100Ω feedline. The equivalent at the junction of the two 100Ω lines is 50Ω. A 50Ω feedline is connected to edge feed [9]. The calculated dimensions are given in table 2:

Radius of the Patch	17 mm
Inter-element spacing	62.5 mm
Width of 100Ω feedline	0.7 mm
Width of 50Ω feedline	3 mm

Table 2: Patch & Feedline Dimensions of 2x1 array

### 3.3 Design Analysis for 4x1 Antenna Array:

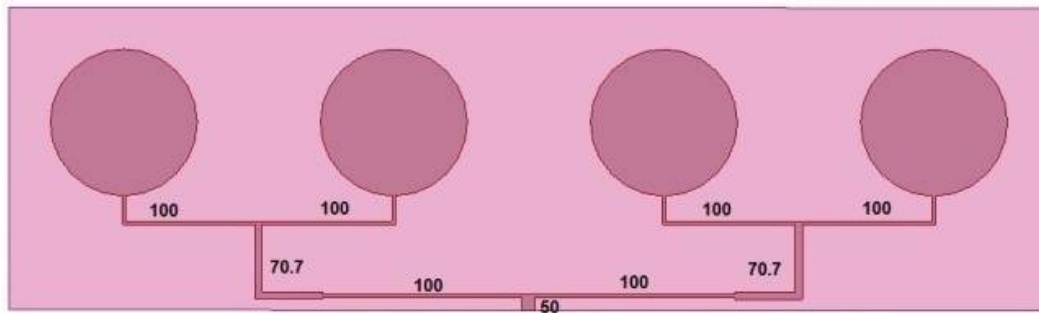
We used the same values of height of the dielectric substrate (h) and the same dielectric material (FR4) at the design frequency.

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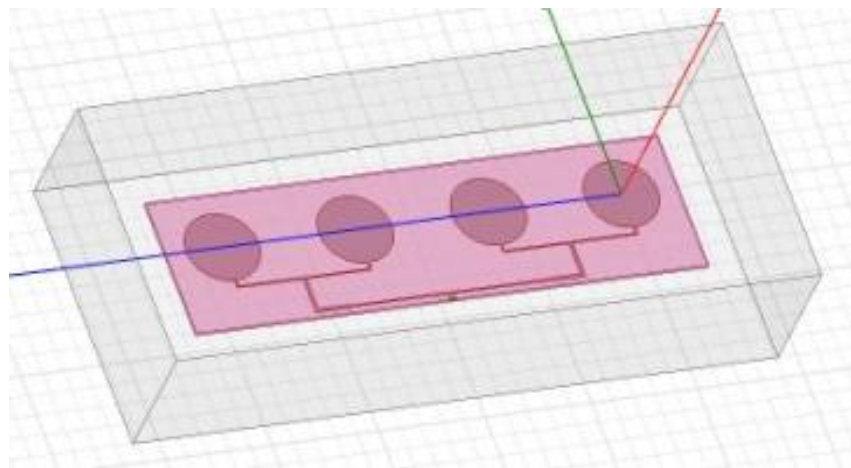
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(a)



(b)

Fig. 3. 4x1 patch antenna array (a) Configuration (b) Design

All the patches are connected to 100Ω lines each. The equivalent at the junctions of each pair is 50Ω. As shown in the above design a quarter wave transformer is placed between a 50Ω equivalent point and 100Ω line whose resultant impedance is calculated as  $Z = \sqrt{Z_{in} * Z_{out}} = \sqrt{50 * 100} = 70.7 \Omega$ . Finally two pairs of 100Ω lines from each side result in an equivalent of 50Ω where the coaxial feeding is considered. The calculated dimensions are tabulated in the table 3:

Radius of the Patch	17 mm
Inter-element spacing	62.5 mm
Width of 100Ω feedline	0.7 mm
Width of 70.7Ω feedline	1.6 mm
Width of 50Ω feedline	3 mm

Table 3: Patch & Feedline Dimensions of 4x1 array

## IV. SIMULATION RESULTS OF CIRCULAR PATCH ANTENNA ARRAYS IN HFSS

The proposed antenna is designed [8 - 9] and simulated in HFSS software. There are three solution types available in HFSS namely Discrete, Fast and Interpolating. Discrete is the most accurate and takes the longest time to simulate out of the three types of solutions. Fast is the least accurate and takes the shortest time for simulation. Interpolating is moderately accurate and takes moderate time for simulation. The designed antennas are analyzed in terms of gain.

## 4.1 Simulation Results of Return Loss and Impedance Bandwidth:

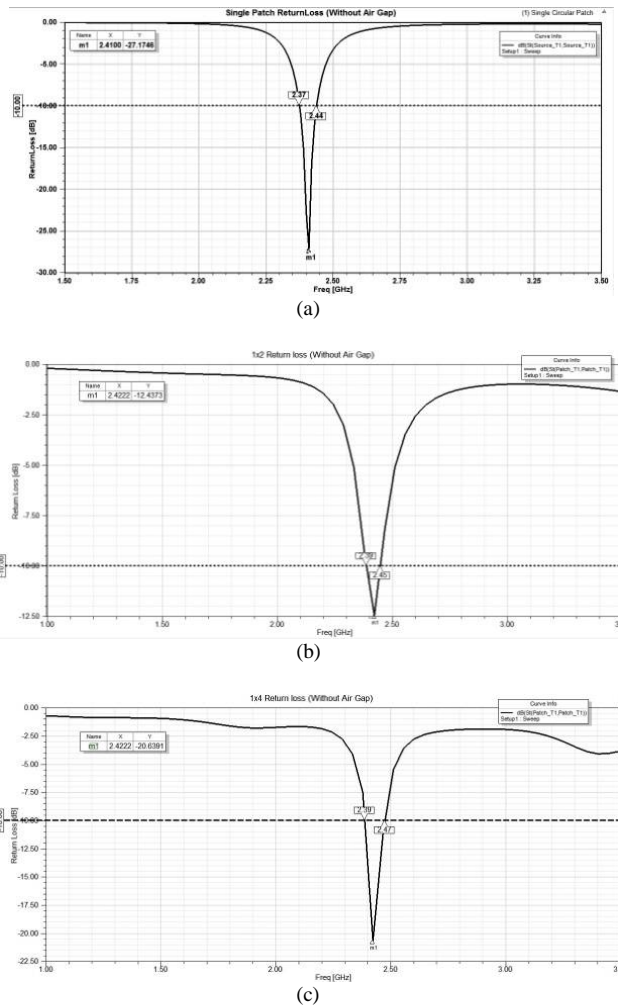


Fig. 4. Return loss  $S_{11}$  obtained for the (a) single patch antenna (b) 2x1 patch antenna array (c) 4x1 patch antenna array

Fig. 4. (a), (b) and (c) shows the Return Loss  $[S_{11}]$  of the proposed antenna in dB.  $S_{11}$  Gives the Return Loss at the feed position where the input to the Microstrip patch antenna was applied. It should be less than -10 dB for an acceptable operation. From the fig. 4. (a), (b) and (c), It is evident that the proposed Circular Single Patch Antenna, 2x1 Circular Patch Antenna array and 4x1 Circular Patch Antenna array are operated at a resonant frequency of 2.4GHz. The Return Loss values were obtained at this resonant frequency are -27.1746 dB, -12.1746 dB and -22.8745 dB respectively shown in table 4.

The simulated impedance bandwidth values are 64.08 MHz, 64.8 MHz and 80 MHz for Single Patch Antenna, 2x1 Circular Patch Antenna array and 4x1 Circular Patch Antenna array respectively that are tabulated in table 4.

## 4.2 Simulation Results of Radiation pattern:

The radiation patterns of the single patch antenna, 2x1 patch antenna array and 4x1 patch antenna array in E-Plane and H-Plane at 2.4GHz are shown in fig. 5. (a), (b) and (c) respectively.

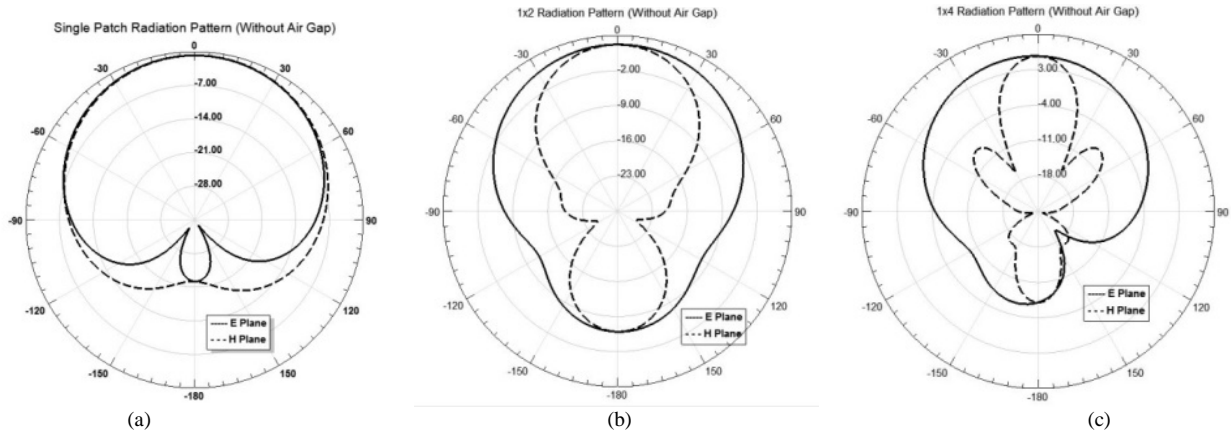
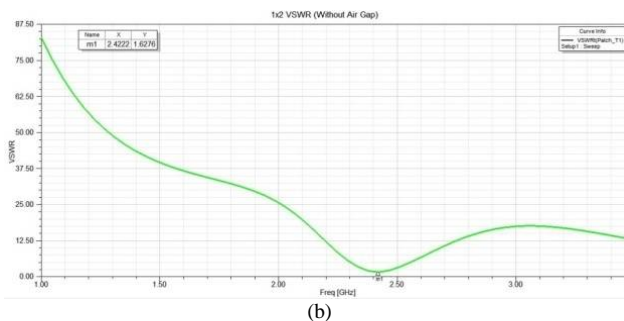
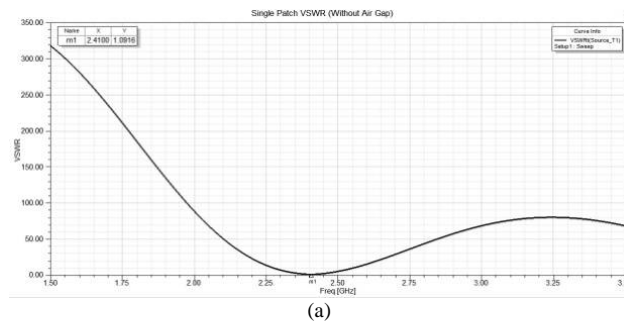


Fig. 5. Radiation Pattern obtained for the (a) single patch antenna (b) 2x1 patch antenna array (c) 4x1 patch antenna array

### 4.3 Simulation Results of VSWR Plot:

Fig.6. (a), (b) and (c) shows the VSWR (Voltage Standing Wave Ratio) plots for the three cases of Circular Single Patch Antenna, 2x1 Circular Patch Antenna array and 4x1 Circular Patch Antenna array respectively. Here the VSWR value for the proposed three cases of Circular Single Patch Antenna, 2x1 Circular Patch Antenna array and 4x1 Circular Patch Antenna array were obtained as 1.0916, 1.6034 and 1.1548 respectively at the resonating frequency of 2.4GHz.





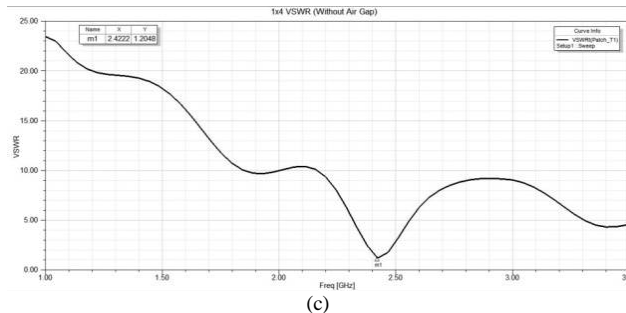


Fig. 6. VSWR obtained for the (a) single patch antenna (b) 2x1 patch antenna array (c) 4x1 patch antenna array

#### 4.4 Simulation Results of Gain and Radiation Patterns:

The peak gain values of the single patch antenna, 2x1 Circular Patch Antenna array and 4x1 Circular Patch Antenna array are 0.72935 dB, 5.7414 dB and 8.2572 dB respectively that are presented in fig. 7. (a), (b) and (c).

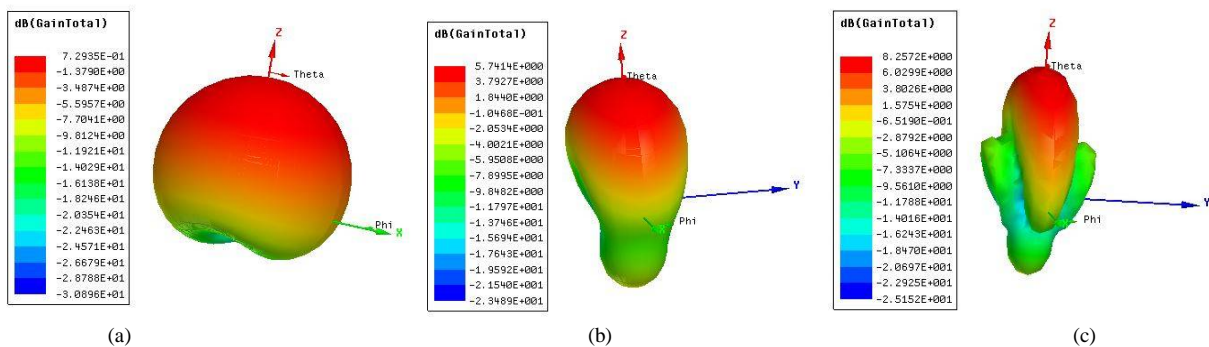


Fig. 7. Gain and 3D Radiation plot for the (a) single patch antenna (b) 2x1 patch antenna array (c) 4x1 patch antenna array

The above simulated results for single patch antenna, 2x1 Circular Patch Antenna array and 4x1 Circular Patch Antenna array are tabulated as below:

Array	Return loss (dB)	Gain (dB)	VSWR	Impedance Bandwidth (MHz)	3dB beamwidth
Single Circular Patch	-27.1746	0.72935	1.0916	64.08 MHz	102.2872
2x1	-12.5887	5.7414	1.6034	64.8 MHz	47.079
4x1	-22.8745	8.2572	1.1548	80 MHz	87.0698

Table 4: Consolidated results obtained for all antennas

#### V. CONCLUSION

Microstrip patch antenna arrays of circular shaped radiating elements were successfully designed and implemented using the FR4 Epoxy Glass substrate. Through the Analysis of HFSS simulation software, it was observed that the antenna resonated at 2.4 GHz frequency. In this work, edge feed technique was used for the simulation of 2x1 Circular Patch Antenna array and 4x1 Circular Patch Antenna array, whereas probe feed technique is used for Single Patch Antenna. From the proposed simulation design, the maximum achieved gain was 8.2572 dB for 4x1 array and 5.7414 dB for a 2x1 array.

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