MAT JOURNALS

Journal of Remote Sensing GIS & Technology
Volume 4 Issue 1

Study and Analysis of Microstrip Patch Array at 12 GHz for 5G Applications

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Abstract

This paper presents a study, analysis of microstrip patch arrays for the 5G application. It is the analysis of a single element, two elements and four elements of microstrip patch designed at 12 GHz. For better impedance matching, corporate feeding network is used in three configurations of an array. Microstrip line and patch are etched on RT Duroid 5880 (dielectric constant of 2.2 and a height of 1.56 mm) substrate material. Corporate feeding is modified and various performance parameters, namely, return loss characteristics, impedance bandwidth, gain, directivity, and radiation patterned are compared with conventional corporate feeding. It is observed an improvement in all performance parameters. From the simulation results of four elements array configuration, it is increased of 120% gain and directivity as compared to a single element configuration. It is also noticed that there is an increase of 478% in impedance bandwidth as compared to a single element configuration. There is decreased of beamwidth in 72% as compared to a single element. Thus, proposed 4-elements microstrip patch array with modified corporate feeding is effective candidate for future 5G applications.

Keywords: *Microstrip Patch Antenna, Array Antenna, Corporate feed Array, HFSS, 5G, 12 GHz.*

INTRODUCTION

Modern Communication Systems demands the use of antennas that are light weight, easy to excite and perform over a wide frequency range and they should be adaptable with changing system requirements or environmental conditions. This has forced the researcher to innovate on different antenna configurations and feed structures that can operate over a wide frequency range with different polarizations simultaneously.

Different types of Array Configurations of microstrip Patch antenna can be used for overcome the constraints of Narrow Bandwidth and Low Gain [1]. In 2009 Design of Corporate fed 2*1 Elements Microstrip Antenna are presented with 20.52% of impedance bandwidth [2]. Advantages of the patch antenna are Low Cost, less weight and less size as well as the High Gain can be achieved by corporate feeding [3].

Typically, main disadvantage of the microstrip patch antenna is its narrow bandwidth. The typical bandwidth of a microstrip patch antenna is around 4% to 7%. Gain of the patch antenna can be increased by using the array. It can be increased up to 3 dB by using the double elements [4]. In recent years, demand of the 5G communication is surprisingly increased. Although Demand of the 5G communication is to achieve High Gain and Better Directivity, Enhanced Bandwidth and reduction of size is also considered, also the Low dielectric constant material can be preferred for good Radiation. A thicker substrate will increase the radiated power, reduce conductor loss and improve impedance bandwidth. For impedance matching purposes, the offset microstrip line feed are easiest to use since the offset depth controls the input impedance of the antenna. But the feed line radiates and causes pattern and polarization degradation. The coaxial feed reduces spurious feed radiation, but it tends to have a narrow bandwidth [5]. In [6] Microstrip Patch Array Antenna with corporate feeding method is described, which operates on the 4.3 GHz. For single element antenna design different types of feeding method like Inset feeding [7], coaxial probe feeding [8], [9] and quarter wave transformer feeding [10] can be used for better performance. The feed of microstrip antenna affects the radiation characteristics of radiating elements, therefore a care must be taken while deciding the proper feed [11]. In this paper quarter wave transformer feeding method is used for antenna design for a single element, two elements and four elements.

Section II Demonstrate the calculation the physical dimensions of Antenna and Section III comprise Procedure of the feed network of a single element, Two elements and Four elements design. Section IV is about to Results and Discussions on the achieved results. Section V gives the conclusion of the presented designs.

CALCULATIONS OF PATCH ANTENNA DIMENSIONS:

For the designing of Microstrip patch antenna first we have to choose Dielectric substrate and Resonate frequency. Parameters of Antenna can be find out by the equations are described below [12],

Find Width of Patch (W) :

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad \text{.......(1)}$$

Where W = width of patch
f_r =Resonate frequency
c = Free space velocity
ε_r =Dielectric constant of substrate

Find Effective Dielectric constant (ε_{reff})

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2\sqrt{1+12\frac{h}{W}}}, \frac{W}{h} > 1 \text{ ....(2)}$$

Where ε_{reff} = Effective Dielectric constant
h = Height of Dielectric substrate

1. Find Length extension (ΔL) :

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \longrightarrow$$

.... (3)

Where ΔL = Length extension

2. Find Actual Length (L) : ⟶

$$L = \frac{Co}{2f_r\sqrt{\varepsilon_r}} - 2\Delta L \qquad \text{........(4)}$$

Where L = Actual Length
Find Dimensions of Ground plane W_g and L_g :

$$W_g = 6h + W \qquad \text{........(5)}$$

$$L_g = 6h + L \qquad \text{........(6)}$$

Where W_g = Width of ground plane
L_g = Length of ground plane

Here desired resonate frequency is 12 GHz, Dielectric constant of substrate (RT Duroid 5880) is 2.2 and Height of the substrate is 1.56mm.

As described in (1) to (6) physical parameter of patch antenna at 12 GHz are listed in table 1.

Table 1. *Patch Dimensions for 12 GHz Antenna*

W	9.88mm
Ereff	1.9526
ΔL	0.7665 mm
L	7.36mm
Wg	15.88mm
Lg	13.36mm

DESIGN PROCEDURE:

The design was carried out using the Ansoft high frequency structure simulator (HFSS) software. The proposed antenna consists of three layers: the top is the radiating element, the middle is a substrate which provides mechanical support for the radiating patch elements as well as to maintain the required precision spacing between the patch and its ground plane, and the bottom is the ground plane which provide support and increase the bandwidth of the antenna in order to meet up the design requirements. RT Duroid 5880 (dielectric constant of 2.2 and height of 1.56 mm) is used for better Impedance Bandwidth.

Design and analysis of single element:
Geometry of single element is shown in the Fig.1.

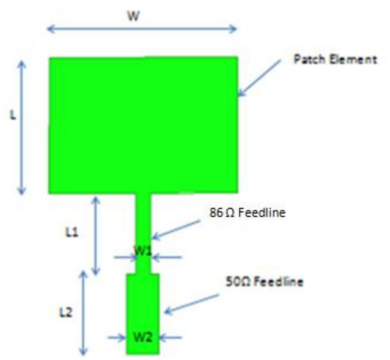

Fig. 1. *Geometry of Single Element antenna at 12 GHz*

[W=9.88 mm, L=7.36 mm, W_1=1.92 mm, L_1=4.2 mm, W_2=4.8 mm, L_2=4.2 mm]
Edge impedance of the antenna can be found out by

$$R_{in} = \frac{1}{(2G_e)} \qquad \text{........(7)}$$

$$G_e = 0.00836\frac{W}{\lambda 0} \qquad \text{.......(8)}$$

Where R_{in} = Edge impedance
G_e = Transconductance of Patch
W = Width of Patch
λ_0 = Free space velocity

For this antenna we get R_{in} =151 Ω

Quarter wave transformer impedance can be found out by,

$$Z_q = \sqrt{R_{in} \times Z_c} \qquad \text{........(9)}$$

Where Z_q = Quarter Wave transformer impedance
R_{in} = Edge impedance,
Z_c =Characteristic impedance(50 Ω)

For proposed design we can get Z_q = 86 Ω
One can find out the width of the microstrip feedline by these equations:

$$Z = \frac{60}{\sqrt{\varepsilon_{reff}}} \ln\left[\frac{8h}{W} + \frac{W}{h}\right]$$
$$\frac{W}{h} \ll 1 \qquad \text{......(10)}$$
$$Z = \frac{120\pi}{\sqrt{\varepsilon_{reff}}} \frac{1}{\left[\frac{W}{h} + 1.393 + 0.667\ln\left(\frac{W}{h} + 1.44\right)\right]}$$
$$\frac{W}{h} > 1 \qquad \text{....... (11)}$$

Design and analysis of two element:
Corporate feeding method is chosen to feed the array elements. In that type of configuration two-way power divider is used which divides 50 Ω feedline into a 100 Ω feedline as depicted in Fig.2. Quarter wave transformers(123 Ω) are used to match the 100Ω lines to the edge impedance (151 Ω).

Geometry of Two elements array is shown in the Fig.2..

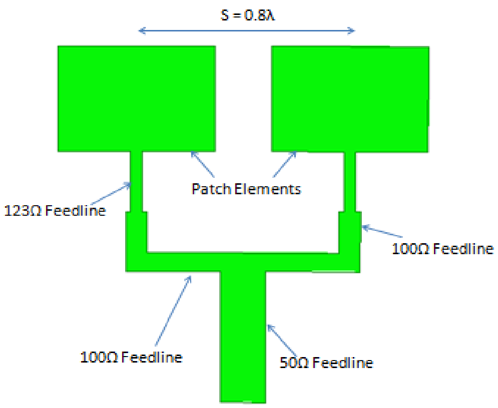

Fig. 2. *Geometry of Conventional Two Elements array with corporate feeding at 12 GHz*

After Calculations we get Width of the strip lines for different impedances by equation (10) and (11).
For 50 Ω = 4.80 mm
For 100 Ω = 1.32 mm
For 123 Ω = 0.74 mm

The cut slots or curved feed performs the major role in radiation for antenna. It distributes power in each patch adequately. By using the cut slots we have modified the conventional design as shown in Fig.3.

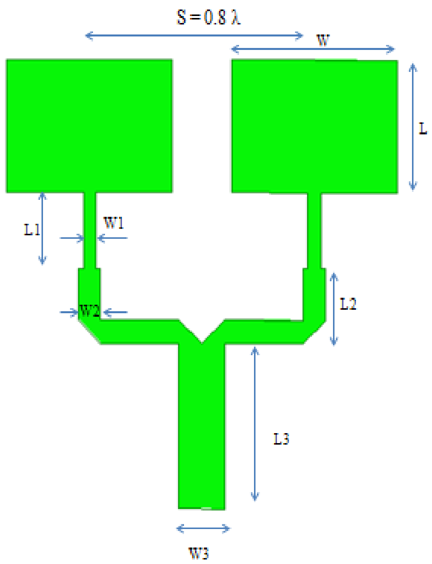

Fig. 3. Geometry of Modified Two Elements array with corporate feeding at 12 GHz
[W=9.88 mm, L=7.36 mm, W_1=0.74 mm, L_1=4.2 mm, W_2=1.32 mm, L_2=4.2 mm, W_3=4.8 mm, L_3=9.1 mm]

Design and analysis of Four elements
In that configuration two-way power divider is used which divides 50 Ω feedline into a 100 Ω feedline , ant to match with the another 100Ω equally divided feedline , 70.7 Ω quarter wave transformers are used. Another Quarter wave transformers (123 Ω) are used to match the 100 Ω lines to the edge impedance (151 Ω) as depicted in Fig.4.

Geometry of four elements is shown in the Fig.4.

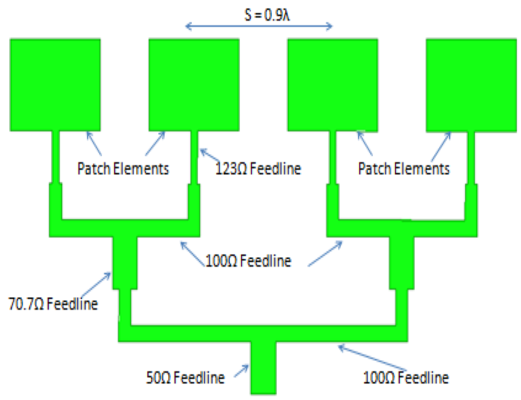

***Fig. 4.** Geometry of Conventional Four Elements array with corporate feeding at 12 GHz*

After Calculations we get Width of the 70.7 Ω strip line is 2.64 mm by equations (9), (10) and (11).
Modified Geometry for the Four element array is shown in Fig.5.

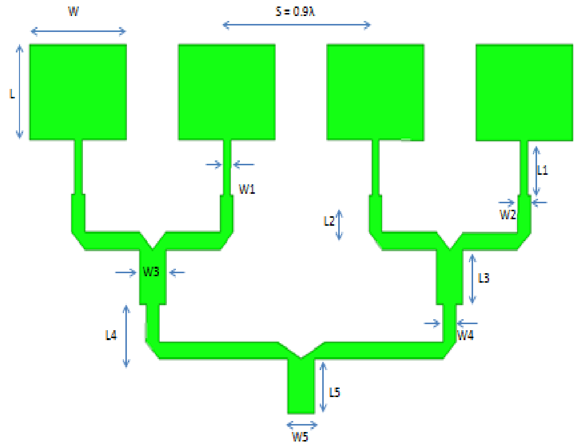

***Fig. 5.** Geometry of Modified Four Elements array with corporate feeding at 12 GHz*
[W=9.88 mm, L=7.36 mm, W_1=0.74 mm, L_1=4.2 mm, W_2=1.32 mm, L_2=4.2 mm, W_3=2.64 mm, L_3=4.2 mm, W_4=1.32 mm, L_4=4.2 mm, W_5=4.8 mm, L_5=4.2 mm]

RESULTS AND DISCUSSIONS:
Single Element Patch Antenna
From Fig.6. single element patch antenna is resonates at 12 GHz and having a return loss of -42dB. Impedance bandwidth is 580 MHz (11.71 GHz – 12.29 GHz) and % Bandwidth of 4.83 %.

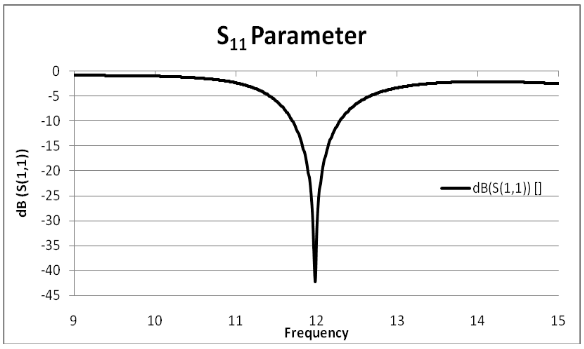

Fig. 6. *S_{11} Parameter for 12 GHz single element antenna*

Radiation pattern of E-plane and H-plane at 12 GHz are shown in Fig 7. It has broad band and linear radiation pattern. Single element antenna has 5.02 dB & 5.07 dB gain and directivity respectively.

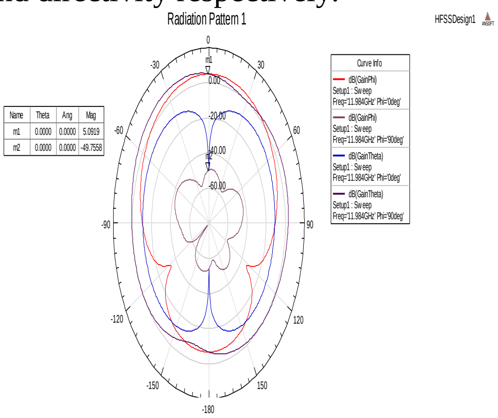

Fig. 7. *Radiation Pattern of 12 GHz Single Element antenna*

Two Element Patch Antenna:
The cut slots or curved feed performs the major role in radiation for antenna. Here we have shown the comparison of S_{11} Parameter between the Conventional Array and Modified Array in Fig.7, which shows the curved feed in modified Array configuration, improves the power spitting in each direction and enhance the radiation characteristics.

Conventional configured antenna resonates at 12 GHz but at return loss of -20 dB where as the Modified array configured antenna resonates at 12 GHz at return loss of -38 dB. According to this analyzed result we can concluded that the modified configured array is better to use than conventional array.

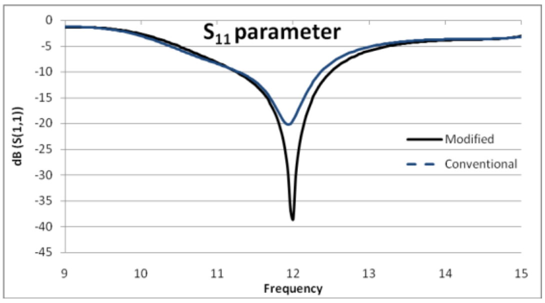

Fig. 8. *Comparison of S_{11} parameter for corporate feeding of Conventional and Modified Antenna with corporate feeding for 12 GHz Two Elements array*

Besides, Main requirement is to E plane separation between two antennas in this type of geometry. It is concluded that for any planner array configuration, optimized antenna characteristics can be obtained depending upon the element spacing. The effect of mutual coupling can be minimized by optimizing the inter element spacing [13].

We have carried out numerical study on E-plane separation between elements (S). For two elements array various S = 0.8λ, λ and 1.5λ are studied and analyzed. Return loss characteristics of these are shown in Fig 6, It is observed that E-plane separation S of 0.8λ has better return loss characteristics (S_{11} = -38 dB) and resonates at 12 GHz as compared to S= λ and 1.5λ. It is concluded that at 12 GHz, S= 0.8λ is optimized separation between two elements for two element array.

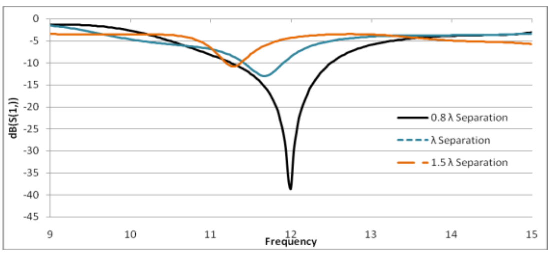

Fig. 9. *Comparison of S_{11} parameter for different separations between two elements for Two Elements array*

From Fig.8 and 9 two elements patch array antenna is resonates at 12 GHz and having a return loss of -38 dB. Impedance bandwidth is 1.24 GHz (11.26 GHz – 12.50 GHz) and % Bandwidth of 10.3 %. It is observed that the bandwidth is increased by 660 MHz (114%) than single element antenna.

Radiation pattern of E-plane and H-plane at 12 GHz are shown in Fig 10. It has broad band and linear radiation pattern. Two element array antenna has 5.16 dB & 5.29 dB gain and directivity respectively.

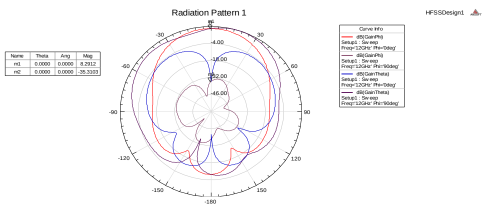

Fig. 10. *Radiation Pattern of Two Elements array with modified corporate feeding at 12 GHz*

Four Element Patch Antenna:

Same like Two elements array antenna the cut slots or curved feed is perform the major role in radiation for four elements also. Here we have shown the comparison between the result of Antennas Geometry of Conventional and Modified S_{11} Parameter in Fig.12.

It is observed that from Fig. 12 the result of configuration of Modified antenna array has better return loss characteristic compare to configuration of Conventional antenna array.

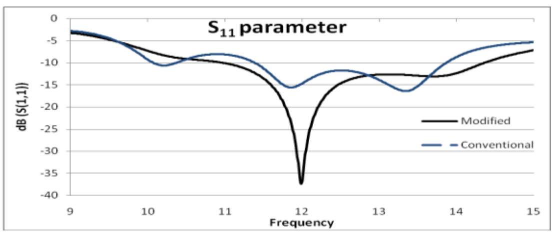

Fig. 11. *Comparison of S_{11} parameter for Patch Geometry of Conventional Array and Modified Array with corporate feeding for Four Elements at 12 GHz*

We have carried out numerical study on E-plane separation between elements (S). For two elements array various S = 0.7λ, 0.8λ and 0.9λ are studied and analyzed. Return loss characteristics of these are shown in Fig 6, It is observed that E-plane separation S of 0.9λ has better return loss characteristics (S_{11} = -37 dB) and resonates at 12 GHz as compared to S= 0.7λ and 0.8λ. It is concluded that at 12 GHz, S= 0.9λ is optimized separation between two elements for four element array.

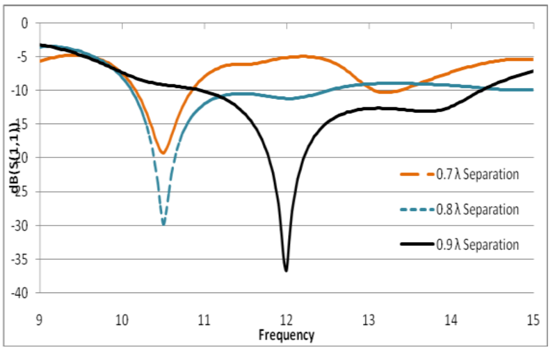

Fig. 12. *Comparison of S_{11} parameter for different separations for Four Elements array with modified corporate feeding configuration*

Fig. 12 shows simulated S parameter of the four elements and it can be seen that it resonates at frequency of 12 GHz, with return loss of -38 dB with the Wide bandwidth of 3.35 GHz. It shows that Bandwidth achieved by Four elements antenna is 2.77 GHz (478 %) Higher than single element antenna and 2.11 GHz (174 %) Higher than a two elements patch array antenna.

Fig. 13 show that the antenna achieves a gain of 11.39 dB and its Directivity is about to 11.51 dB. The gain is achieved approximately 6 dB (120 %) higher than the single element antenna and 3 dB (37 %) Higher than Two elements array antenna.

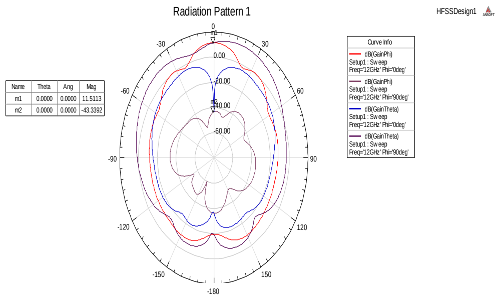

Fig.13. *Radiation Pattern of Four Elements array with modified corporate feeding at 12 GHz*

Comparison of Antenna Parameters:
Comparison of the S_{11}Parameter of all antennas with optimized separation and modified configuration are shown in the Fig. 14.

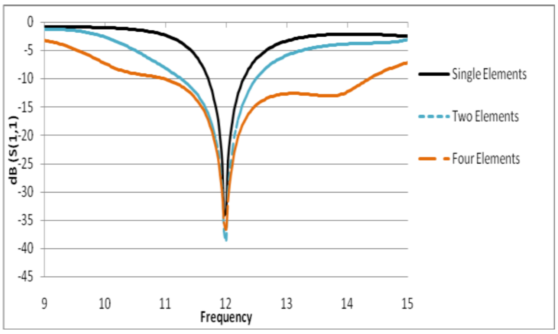

Fig. 14. *Return loss characteristics of modified configuration with corporate feeding for three antennas.*

Table No. 3 Shows the overall comparison of the antennas performance parameters and it shows that Gain as well as the Bandwidth of the antenna increases when increase the antenna elements.

Table 3. *Comparison of the antennas performance parameters for single element, two elements and four elements Antennas*

Parameters	**Single Element**	**Two Elements**	**Four Elements**
Return loss	-42 dB	-38 dB	-38 dB
Gain	5.02 dB	8.16 dB	11.39 dB
Directivity	5.07 dB	8.29 dB	11.51 dB
Impedance Bandwidth	580 MHz	1.24 GHz	3.35 GHz
% Bandwidth	4.83 %	10.3 %	27.9 %
Beam width	78 ˚	48 ˚	22 ˚
Efficiency	99 %	98 %	99 %

From the Table 3 it is observed the improvement in all performance parameters. From the simulation results of four elements array configuration, it is increased of 120 % gain and directivity as compared to single element configuration. It is also noticed that there is increase of 478 % in impedance bandwidth as compared to single element configuration. There is decreased of beamwidth in 72 % as compared to single element.

CONCLUSION
In presented work Single element antenna, two elements array and four elements array with optimized separation are designed and analyzed. For an array antenna with a number of patch elements are improves Gain, Bandwidth as well as Directivity. Separation between two elements performs the major role in antenna performance. Additionally Cut slots in the feedline can also improve the power radiating capability and improve the performance. It is observed that the Single element antenna achieves the gain of 5.02 dB with the Bandwidth of 580 MHz, 2*1 elements array achieves the gain of 8.16 dB with the bandwidth of 1.24 GHz, 4*1 elements array has the wide Bandwidth as 3.35 GHz and high gain of 11.29 dB. All presented antennas are good competitors for future 5G Communications and can be used for the 5G systems like WLAN, WiMax.

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