Study and Analysis of Rectangular Microstrip Patch Array Antenna at 28GHz for 5G Applications

MOHAMED F. ABDULMAJID
Department of Communication College of Electronic
Technology Bani-Walid, LIBYA

Abstract—Fifth generation (5G) is the next major phase of mobile telecommunications standards beyond the current 4G, which will operate at millimeter-wave frequency band. In any wireless device, the performance of radio communications depends on the design of an efficient antenna. This paper presents designs for rectangular microstrip antennas (single element, two elements, four elements and eight elements at 28 GHz), where 28GHz is one of the standard frequencies of the 5G communications. For better impedance matching, corporate feeding network is used in array configuration. Microstrip line and patch are etched on RT Duroid 5880 (dielectric constant of 2.2 and a height of 0.5 mm) substrate material. Array antenna improves various performance parameters, namely, return loss characteristics, impedance bandwidth, gain, directivity, and radiation pattern. It is observed an improvement in most parameters. From the simulation results of eight elements array configuration, it is increased of 95.15% gain and directivity as compared to a single element configuration. It is also noticed that there is an increase of 148.54% in impedance bandwidth as compared to a single element configuration. There is decreased of beamwidth in 52.06 % as compared to a single element. Thus, proposed eight 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, 28 GHz.

1. Introduction

5th Generation is considered as beyond 2020 mobile communications. These standards are developed to serve the current and future demands of the mobile users. But, the mobile traffic worldwide is increasing exponentially each year and the trend will likely continue for the expected future. In recent years, numerous research foundations and industry partners have been researching the concept of a 5th generation (5G) mobile network improvements in capacity, latency, and mobility [1], [8]. Due to spectrum shortage in the conventional microwave bands, millimeter wave (mm-Wave) bands have been attracting great attention as an additional spectrum band for 5G cellular networks. Moving to the mm-Wave frequencies for 5G mobile stations requires new techniques in the design of antennas for mobile-station (MS) and base-station (BS) systems.

In order to achieve an efficient beam-steerable phased array antenna, which is one of the most important parts for 5G cellular systems, the smaller antennas arranged as an array can be employed .The number of devices could reach the tens or even hundreds of billions by the time 5G comes to fruition, due to many new applications beyond personal communications. Bearing in mind the above considerations, microstrip array antennas with corporate feeding technique are discussed in this study. All these antennas are targeted to operate at a 28 GHz frequency band and produce end-fire radiation pattern for 5G communication [2]. Microstrip patch antenna has the advantages of simple to manufacture or fabricate, low cost, easy to form a large array and has light weight. However, it has some setbacks such as low gain and low bandwidth, but can be compensated using a thick substrate with low dielectric constants [3].

2. Single Element Design

There are many shapes for microstrip patch antenna such as circular, square, elliptical, rectangular…etc. Here, the rectangular type was used for its simplicity and popularity.
As there are four different types to feed single patch element antenna, they are edge feed with quarter wave transformer, inset feed, probe feed with a gap, aperture coupled feed, edge feed with gap and two layer feed. In this study, edge feed with quarter wave transformer was applied [4], [6].
For the designing of microstrip patch antenna, dielectric substrate and resonate frequency first must be chosen. Parameters of Antenna can be find out by the equations are described below, to find width of patch (W):

$$W=\frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

Where W = width of patch, f_r =resonate frequency, c = free space velocity, ε_r =dielectric constant of substrate.
Effective dielectric constant (ε_{reff}) is given as:

$$\varepsilon_{reff}=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2\sqrt{1+12\frac{h}{w}}} \tag{2}$$

Where ε_{reff} = effective dielectric constant, h = height of dielectric substrate [5], [7].
Length extension (ΔL) of patch is:

$$\frac{\Delta L}{h}=0.412\frac{(\varepsilon_{reff}+0.3)(\frac{w}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{w}{h}+0.8)} \tag{3}$$

The actual length (L) is given as:

$$L=\frac{c}{2f_r\sqrt{\varepsilon_r}}-2\Delta L \tag{4}$$

Here desired resonate frequency is 28 GHz, dielectric constant of substrate (RT Duroid 5880) is 2.2 and height of the substrate is 0.5mm.
The characteristic impedance ($Z_0 = 50\Omega$), so it can be calculated width of feed line (W_2) as follows:

$$B=\frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}$$

$$\frac{W_2}{h}=\frac{2}{\pi}\{B-1-\ln(2B-1)+\frac{\varepsilon_r-1}{2\varepsilon_r}[\ln(B-1)+0.39-\frac{0.61}{\varepsilon_r}]\} \tag{5}$$

Edge impedance of the antenna can be found out by

$$G_1=\frac{1}{90}(\frac{\omega}{\lambda_0})^2$$

$$R_{in}=\frac{1}{2G_1} \tag{6}$$

Where R_{in} = edge impedance, G_1 = transconductance of patch, W = width of patch, λ_0 = free space wavelength [9]. Quarter wave transformer impedance can be found out by,

$$Z_q = \sqrt{R_{in} Z_0} \tag{7}$$

Length of quarter wave transformer is quarter of wavelength which

$$L_1 = \frac{\lambda_g}{4}$$
$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{reff}}} \tag{8}$$

As can be calculated width of quarter wave transformer as shown below [10]:

$$A = \frac{Z_q}{60}\sqrt{\frac{\varepsilon_r+1}{2}} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right)$$
$$\frac{W_1}{h} = \frac{8e^A}{e^{2A}-2} \tag{9}$$

As described in (1) to (4) physical parameters of patch antenna at 28 GHz are listed in Table I.

TABLE I. PATCH DIMENSIONS FOR 28 GHZ ANTENNA

W	4.22mm	**L**	3.27mm	W_1	0.24mm
ε_{reff}	1.986	W_2	1.5mm	Z_q	119.93Ω
ΔL	0.257mm	**Sub_L**	8.27mm	R_{in}	287.68 Ω
L_1	1.94mm	L_2	3mm	**Sub_W**	8.22mm

Where Sub_L= length of substrate, Sub_W= width of substrate. Geometry of single element is shown in the Fig. 1.

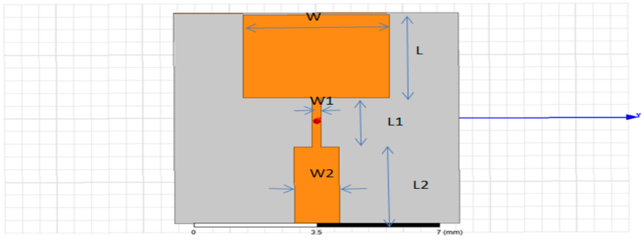

Fig. 1. Geometry of Single Element antenna at 28 GHz

3. Design and Analysis of Two Elements Array

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 feed line into 100 Ω feed lines as depicted in Fig. 2. Quarter wave transformers (119.93 Ω) are used to match the 100Ω lines to the edge impedance (287.68 Ω). Geometry of two elements array is shown in the Fig. 2.

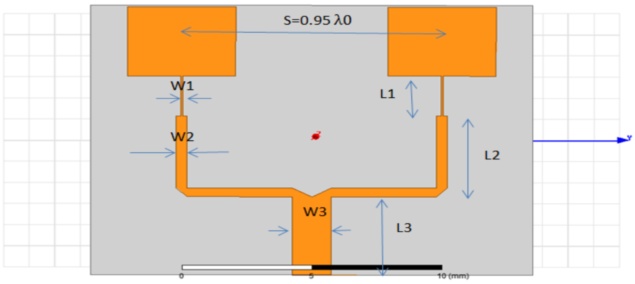

Fig. 2. Geometry of two elements array antenna at 28 GHz.

After Calculations, it can be shown width and length of the strip lines for different impedances by equations (5) and (9) as well as the other parameters in Table II.

TABLE II. DIMENSIONS OF TWO ELEMENTS ARRAY ANTENNA

W	4.22mm	**Sub_L**	12.77mm	L_3	3.7mm
W_1	0.08mm	L	3.27mm	**Sub_W**	17.22mm
W_2	0.41mm	L_1	1.89mm		
W_3	1.5mm	L_2	3.82mm		

4. Design and Analysis of Four Elements Array

In that configuration two-way power divider is used which divides 50 Ω feed line into 100 Ω feed lines , and another is used which divides 100 Ω feed line into 200 Ω feed lines, 239.86 Ω quarter wave transformers are used to match the 200 Ω lines to the edge impedance (287.68 Ω) as depicted in Fig. 3. Geometry of four elements is shown in the Fig. 3.

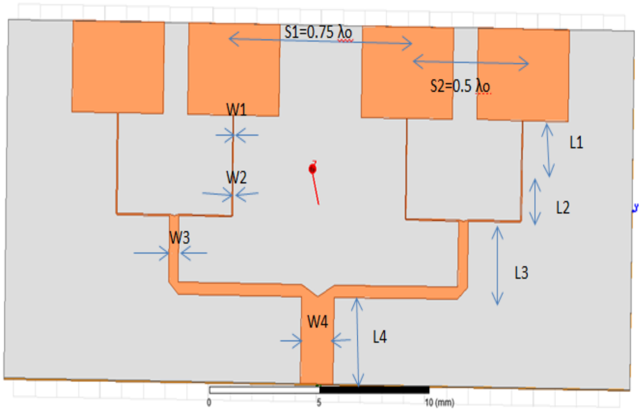

Fig. 3. Geometry of four elements array antenna at 28 GHz.

Table III shows dimensions of the four elements microstrip array antenna using the previous equations.

TABLE III. DIMENSIONS OF FOUR ELEMENTS ARRAY ANTENNA

W	4.22mm	W_4	1.5mm	L_2	1.74mm
W_1	0.046mm	**Sub_L**	12.80mm	L_3	2.8mm
W_2	0.051mm	L	3.27mm	L_4	3.1mm
W_3	0.438mm	L_1	1.89mm	**Sub_W**	28.91mm

5. Design and Analysis of Eight Elements Array

In this method two-way power divider is used which divides 50 Ω feed line into 100 Ω feed lines , 70.7 Ω quarter wave transformers are used to match the 100 Ω feed lines to 50 Ω feed lines, then another power divider is used which divides 50 Ω feed line into 100 Ω feed lines and another is used which divides 100 Ω feed line into 200 Ω feed lines. Finally, 239.86 Ω quarter wave transformers are used to match the 200 Ω lines to the edge impedance (287.68 Ω) as depicted in Fig. 4.

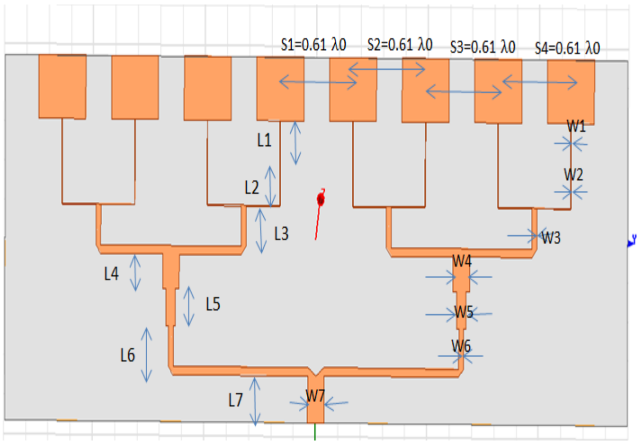

Fig. 4. Geometry of eight elements array antenna at 28 GHz.

Table IV shows dimensions of the eight elements microstrip array antenna using the previous equations.

TABLE IV. DIMENSIONS OF EIGHT ELEMENTS ARRAY ANTENNA

W	4.22mm	W_4	1.5mm	Sub_L	18.735mm
W_1	0.046mm	W_5	0.84mm	L	3.27mm
W_2	0.053mm	W_6	0.438mm	L_1	1.89mm
W_3	0.438mm	W_7	1.5mm	L_2	2.5mm
L_3	2.5mm	L_5	1.89mm	L_7	2.4mm
L_4	1.78mm	L_6	2.5mm	Sub_W	55.82mm

6. Results and Discussions

6.1. Single Element Patch Antenna

From Fig. 5, single element patch antenna is resonates at 28GHz and having a return loss of -31.96dB. Impedance bandwidth is 1.029 GHz (27.5098 GHz – 28.539 GHz) and % Bandwidth of 3.67 %.

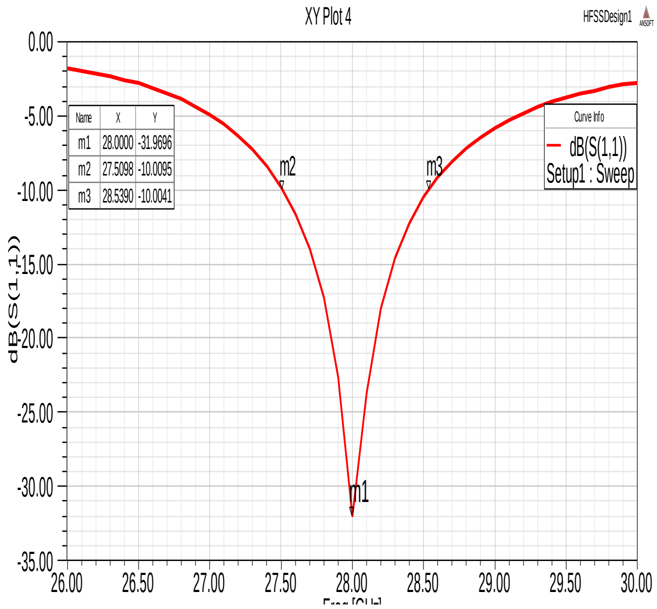

Fig. 5. S11 Parameter for 28 GHz single element antenna.

Fig. 6 and Fig. 7 show the gain of 8.04 dB and directivity of 8.14 dB, consquently, radiation efficiency is 97.7%. Radiation pattern of E-plane and H-plane at 28 GHz are shown in Fig. 6. Half power beam width is 57.58^0 for H-plane and 74^0 for E-plane.

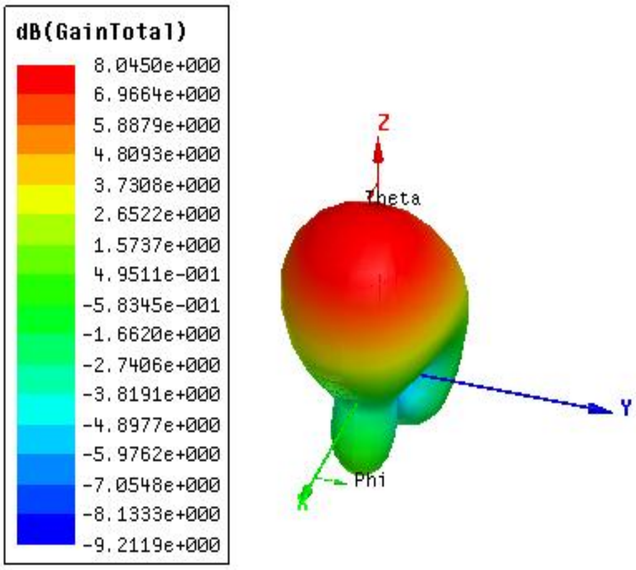

Fig. 6. 3D polar plot for gain of single element antenna.

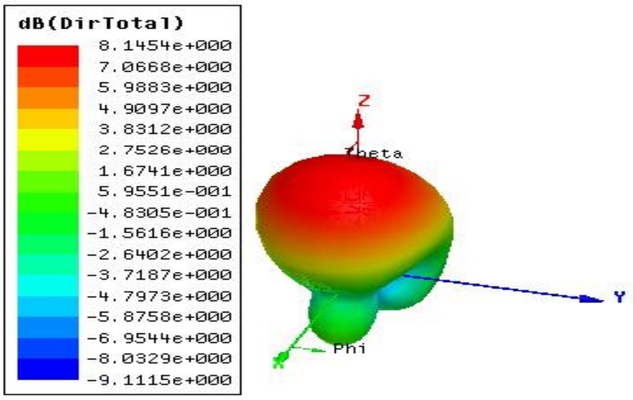

Fig. 7. 3D polar plot for directivity of single element antenna.

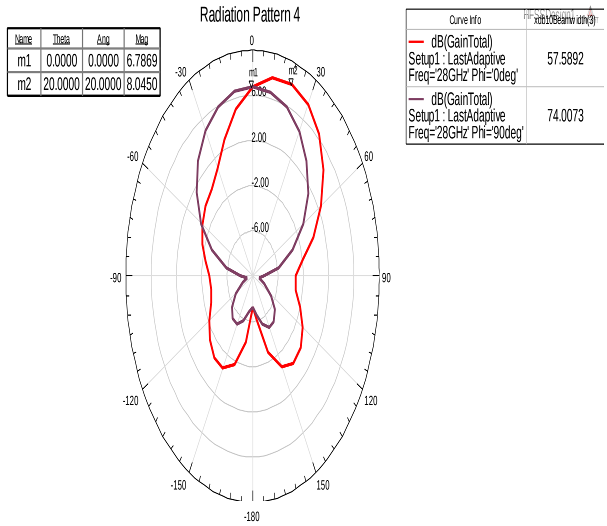

Fig. 8. Radiation pattern of single element antenna.

6.2. Two Elements Patch Array Antenna

Two elements array antenna has less return loss of 19.27dB as shown in Fig. 9. Also, impedance bandwidth is 1.488 GHz (27.173 GHz – 28.661 GHz) and % Bandwidth of 5.31%.

This antenna has 11.05 dB & 11.26 dB gain and directivity respectively as shown in Fig. 10 and Fig. 11. It can be concluded radiation efficiency is 95.33%. Fig. 12 illustrates radiation pattern of E-plane and H-plane. It shows half power beam width is 50.7^0 for H-plane and 29.88^0 for E-plane.

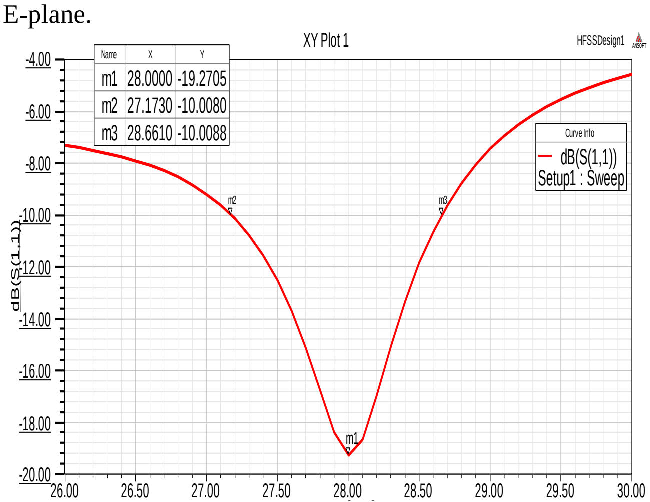

Fig. 9. S11 Parameter for two elements array antenna.

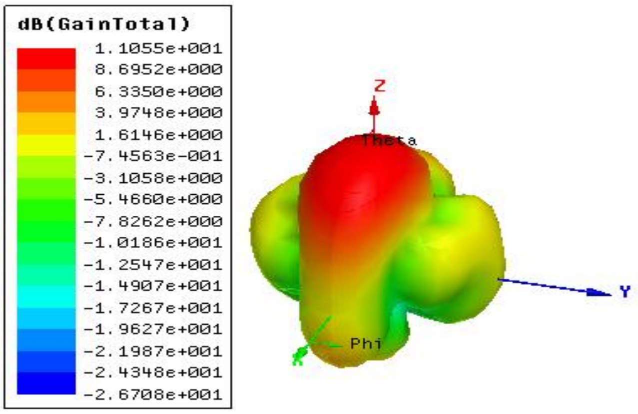

Fig. 10. 3D polar plot for gain of two elements array antenna.

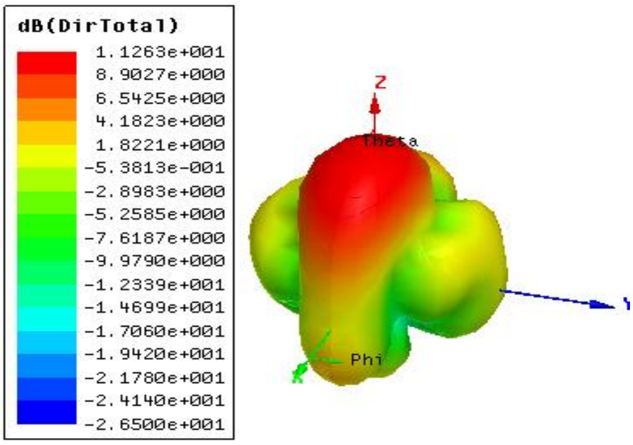

Fig. 11. 3D polar plot for directivity of two elements array antenna.

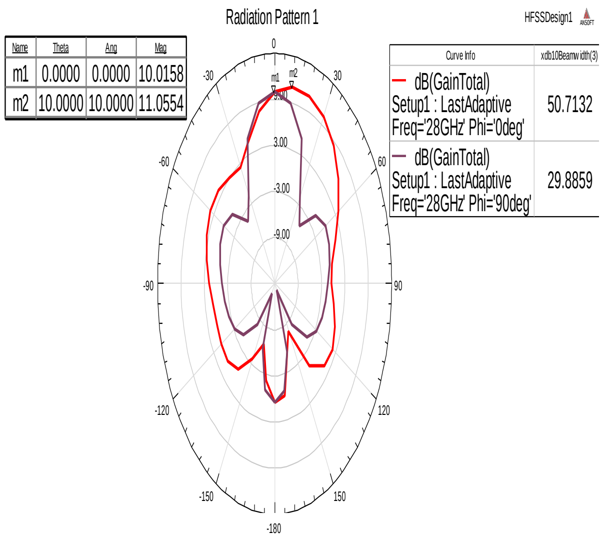

Fig. 12. Radiation pattern of two elements array antenna.

6.3. Four Elements Patch Array Antenna

It can be noted return loss decreases to -18.8dB in four elements array antenna as seen in Fig. 13. In the opposite, impedance bandwidth increseses to 1.99 GHz (26.855 GHz – 28.845 GHz) and % Bandwidth of 7.11%.

As expected the gain of this antenna increases to 13dB and directivity up to 13.11 dB as shown in Fig.14 and Fig. 15, so the radiation efficiency is still high of 97.46%.

Fig. 16 shows radiation pattern of E-plane and H-plane. It illustrates half power beam width is 39.09^0 for H-plane and 19.91^0 for E-plane.

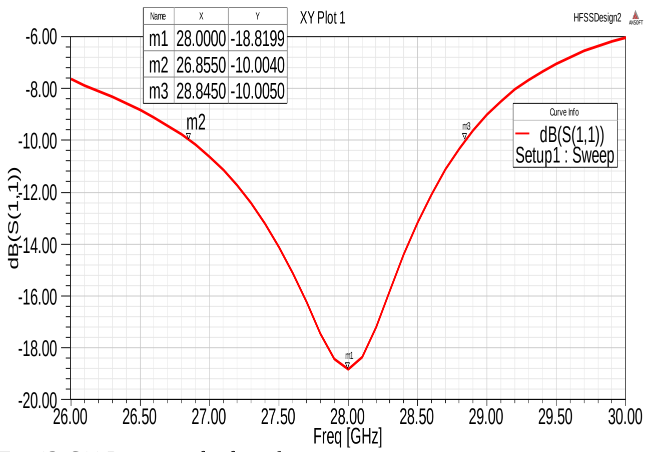

Fig. 13. S11 Parameter for four elements array antenna.

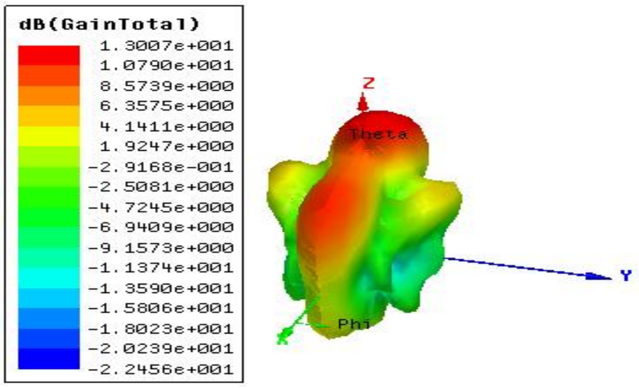

Fig. 14. 3D polar plot for gain of four elements array antenna.

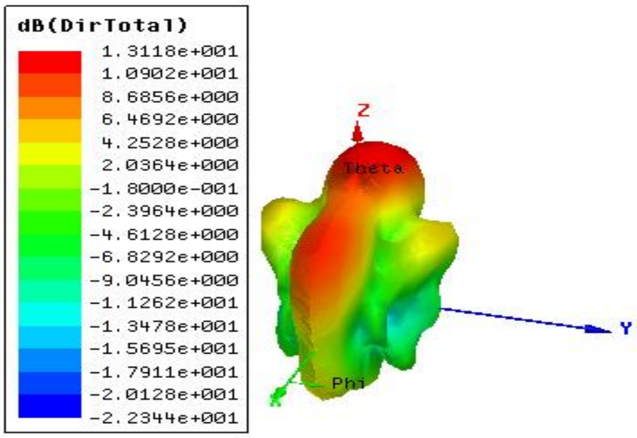

Fig. 15. 3D polar plot for gain of four elements array antenna.

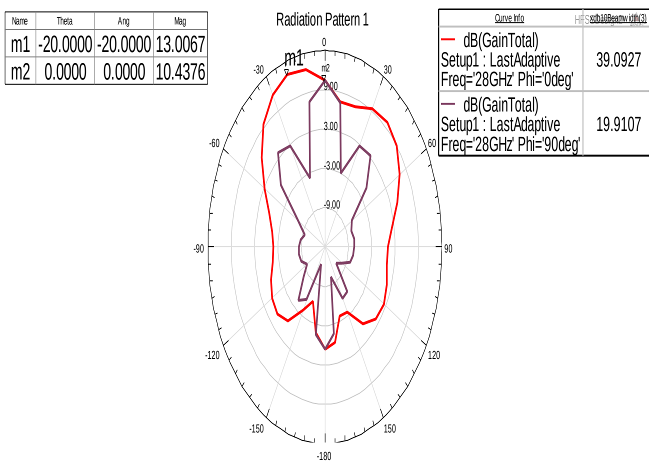

Fig. 16. Radiation pattern of four elements array antenna.

6.4. Eight Elements Patch Array Antenna

It can be noted return loss is the best than the previous antennas, it is -36.7dB as seen in Fig. 17. Impedance bandwidth increases to 2.56 GHz (26.094 GHz – 28.65 GHz) and % Bandwidth of 9.13%.

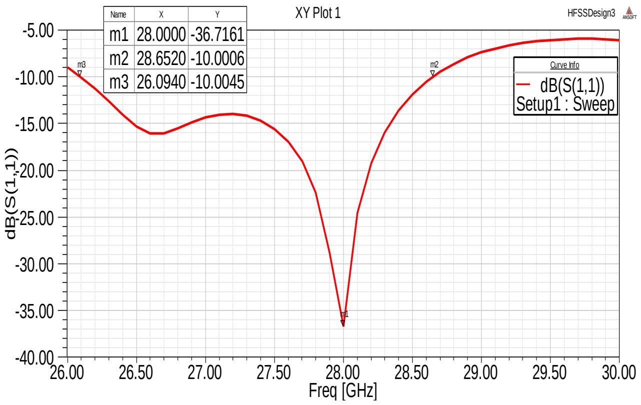

Fig. 17. S11 Parameter for eight elements array antenna.

The gain of this antenna increases to 15.69dB and directivity up to 15.96 dB as shown in Fig. 18 and Fig. 19, so the radiation efficiency is 93.95%.

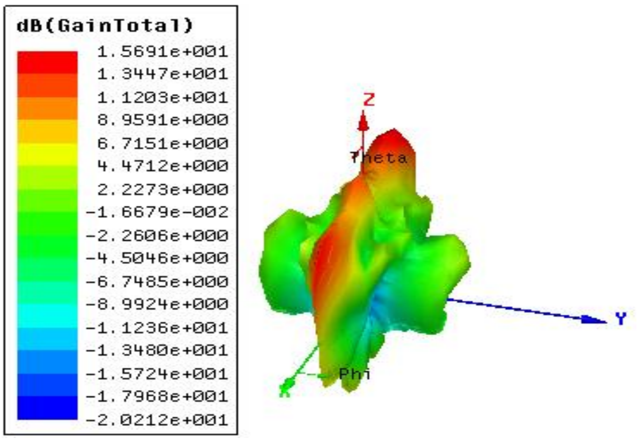

Fig. 18. 3D polar plot for gain of eight elements array antenna.

Fig. 20 shows radiation pattern of E-plane and H-plane. It can be concluded half power beam width is 27.62^0 for H-plane and 4.82^0 for E-plane. As can be noted H-plane is better than E-plane in terms of gain, in other words, the maximum gain for eight elements array antenna in H-plane is 9.97dB, in the opposite, the maximum gain in E -plane is 9.97dB only.

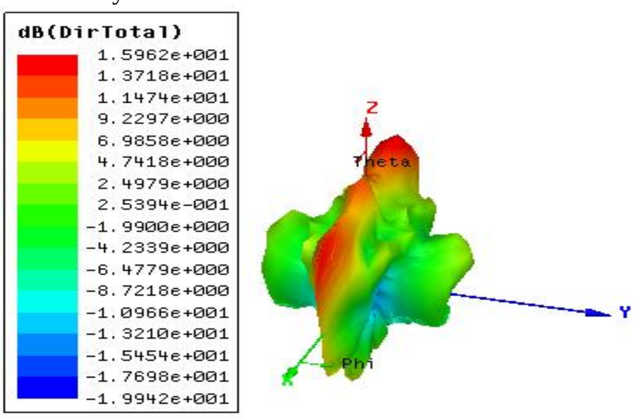

Fig. 19. 3D polar plot for directivity of eight elements array antenna.

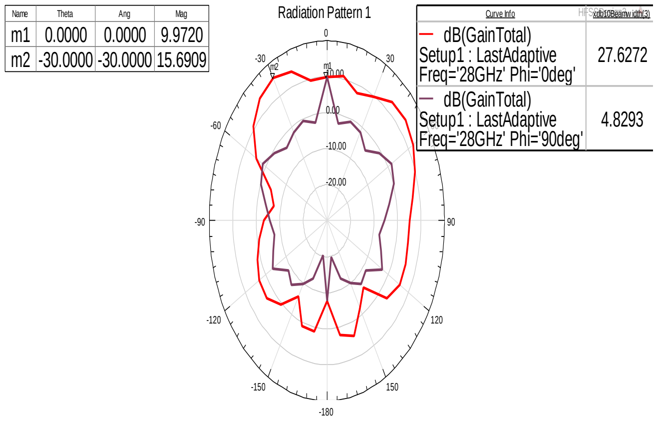

Fig. 20. Radiation pattern of eight elements array antenna.

7. Conclusion

In this study, 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 result in improvement of Gain, Bandwidth as well as Directivity. Separation between two elements performs major role in antenna performance. Additionally Cut slots in the feed line can also improve the power radiating capability and improve the performance. It is observed that the Single element antenna achieves the gain of 8.04 dB with the Bandwidth of 1.03 GHz, two elements array antenna achieves the gain of 11.05 dB with the bandwidth of 1.49 GHz, four elements array antenna has bandwidth as 1.99 GHz and gain of 13 dB, eight elements array antenna has maximum bandwidth as 2.56 GHz and high gain of 15.69 dB. All presented antennas are good competitors for future 5G Communications.

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