Design and Analysis of Microstrip Patch Antenna Arrays for Millimeter Wave Wireless Communication

Md. Farid Shah, Aheibam Dinamani Singh

***Abstract:** In present 4G the enormously growing of cellular user and the shortage of bandwidth which results in difficulty to provide a high data rate to each end user. To achieve wider bandwidth millimeter wave technology is considered to solve the problem of bandwidth shortage. This paper presents a 4x1 element circular phase array of inset fed rectangular patch antenna operating in the millimeter wave band (24.81GHz 33GHz). To achieve large impedance bandwidth the array is designed with edge coupled parasitic patch arrangement which provides dual resonance. The designed array used the ring-shaped sequential rotation feeding line to reduce the unwanted side lobe radiation. The design antenna array achieved good return loss – 10dB ≤ S_{11} ≤ – 18.64dB and maintaining 26% (24.81GHz 33GHz) bandwidth. The antenna array has achieved good return loss S_{11}, -18.64dB at 29.09GHz and VSWR ≤ 1.85 (24.81GHz-33GHz). In millimeter wave wireless communication require high gain antenna to overcome the problem of path loss. The designed array has achieved 10.14dB gain. So the designed will be suitable for the future millimeter-wave wireless communication system.*

***Keywords :** 5G, Millimeter Wave (mmWave) antenna, Long Term Evolution (LTE), Microstrip Patch Antenna (MPA), Coplanar Waveguide (CPW)*

I. INTRODUCTION

Over the last decade Scientists, Researchers and Industries exploring mm wave and cm waveband to solve the problem of bandwidth shortage for transmitting uninterrupted high-resolution video, high data rate for mobile communication. Now millimeter wave technology is considered to solve the problem of bandwidth shortage [1]. With growing number of cellular user the mobile traffic demand is increasing day by day. In present 4G LTE has a peak data rate of 100Mbps for fast-moving vehicle (up to 360 km/h) and 1Gbps for motionless or walker mobile customer. The 4G data speeds drop significantly during peak hours and difficult to provide high data rate to the end user.

The challenges demand of thousands of traffic in future 2020 and beyond will unable to meet by the present LTE technology [2][3]. According to CISCO the monthly global mobile data traffic by 2021 will be 49 exabytes and annual traffic will exceed half a zettabyte. Mobile will represent twenty percent of total IP traffic.

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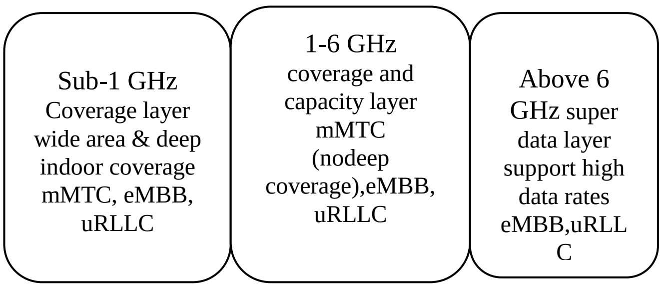
Now the researcher planning 5G to solve worldwide 4G data congestion. The technology that satisfying ITU IMT-2020 requirements and 3GPP Release 15 is refer as 5[th] Generation Wireless System (5G). The design goals of 5G are 20Gb/s peak data rate, 100Mb/s user endured data rate, 10Mbps/m^2 area traffic capacity, 106 devices/km^2 connection density, 1ms latency, mobility up to 500km/h, backward compatibility to LTE/LTE-Advanced and forward compatibility to potential future evolution.

In 5G there are many anticipation such as self driving car, mission critical broadcast, industry and vehicular automation, smart city camera, sensor network, remote area medical treatment, office in cloud, multi person video call etc. The devices in 5G should be artificial intelligence and capable to communicate with machine. Super high-capacity and ultra-high-speed data with fresh cost-efficient are needed. The 5G is not a single technology. It is the ecosystem of wireless networks operating scenarios. The designed is the shift from a single regulation system to a multi regulation system. The frequency spectrum vital choice for 5G attention as follows.



Globally many countries researcher are going research on different frequencies for the 5G frequency spectrum. Table I shows the frequency spectrum consideration for 5G.

Table I. 5G Frequency Spectrum Consideration

Low band below 1Ghz	Mid band 1Ghz to 6GHz	High bands above 24 GHz (mmWave)
600MHz 700MHz 850/900MHz	3.4-3.8GHz 3.8-4.2GHz 4.4 -4.9GHz	24.25-27.5GHz 27.5-29.53GHz 37-40GHz 64-71GHz

In higher millimeter wave frequency has the challenges such as high path loss, high penetration loss through buildings, high foliage loss and LOS propagation makes it weak to moving subscriber by blocking. At higher frequency, 60GHz and beyond the application are limited for indoor and short-range scenario due to high absorption rate by oxygen and the surrounding environment. [5],[6]. The frequency 26.5GHz-40GHz will be a more appropriate band in 5G mobile communication for outdoor applications [1][7]&[8].

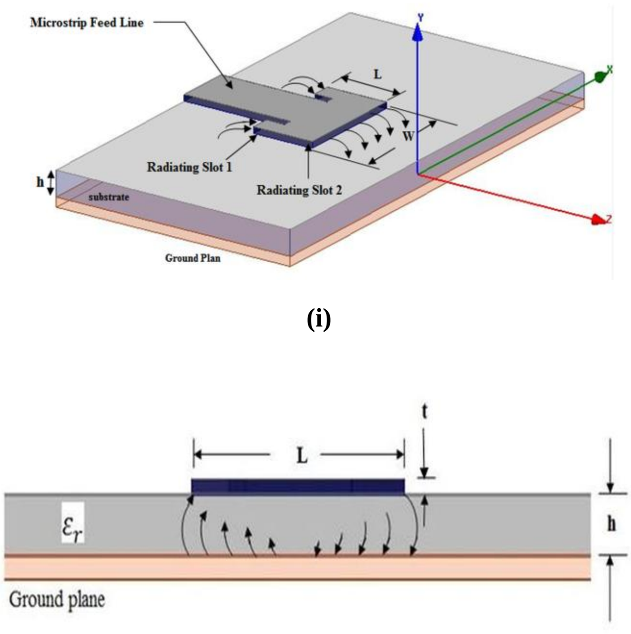
Recently South Korea has auction the 3.5GHz and 28GHz for 5G spectrum. The Federal Communications Commission (FCC) USA has announced 27.5GHz - 28.35GHz for 5G Spectrum. The International Telecommunication Union (ITU) will soon decide officially the frequency spectrum allocations for 5G. A very narrow beam is needed for point-to point links. It will reduce interfering with other cells to access the network. And has advantages of huge unlicensed bandwidth and the size of the antenna is also smaller.

In [1] 25% impedance bandwidth with multiple ports feeding on a 2x2 multilayer structure of dual polarized antenna array is reported. To achieve the same polarization in a multi-port feeding antenna array, the port to port isolations is one of the main challenges. The various feeding techniques of antennas have been developed such as coaxial feed, coplanar feed, proximity-coupled microstrip feed, aperture-coupled microstrip feed, coplanar waveguide feed, series feed, and corporate feed, have been discussed in [9] [21]. An 8x8 corporate feed microstrip antenna array and electromagnetic coupled antenna array have achieved 17% bandwidth using RT Duroid 5880 with $\varepsilon_r = 2.2$, h= 0.254mm and $\delta = 0.001$ at Ka-band, are presented in [18].

In this paper, a 4x1 antenna array is designed using RT Duroid 5880 with $\varepsilon_r = 2.2$, h = 1.6mm and $\delta = 0.001$as substrate with a single feeding port and sequential rotation feeding line on a single layer antenna structure. To achieve large impedance bandwidth, the design antenna array used edge–coupled parasitic patch.

II. DESIGN OF SINGLE AND ARRAY INSET FED MICROSTRIP PATCH ANTENNA

There are many different design of modern microstrip patch antenna such as Inverted-F Antenna (IFA), Planar inverted-F Antenna (PIFA), Folded Inverted Conformal Antenna (FICA) and Electromagnetic Band Gap Antenna (EBG). Among Microstrip Patch Antenna the Inset Feed Microstrip Patch Antenna are easy to design and fabricate, low cost, low profile and light weight [9][10]. In this section include a designed of the single element and its array.



(i)

(ii)

Fig.1: Structural view of Inset Feed MPA (i) Isometric view and (ii) Side view.

A. Design Of Single Element

The field distribution and the geometric structure of Inset Feed Microstrip Patch Antenna is shown in Figure1. The Inset Feed Microstrip Patch Antenna input impedance mainly depend on the inset distance Y_o and inset gap I_g between patch and feeding microstrip line. When a change in inset width effect the value of resonant frequency but the change in the inset length doesn't affect the resonant frequency.

Using RT Duroid 5880 as a substrate, the antenna is designed at 31GHz as the center frequency with h = 1.6 mm and material tangential loss tan $\delta = 0.001$. In this paper, the different parameters value of the single element Inset Feed Microstrip Patch antenna design are calculated from Balani [11] as follows,

(a) *Patch Width* (W)

Width of Patch:

$$W = \frac{C}{2 f_0 \sqrt{\frac{(\varepsilon_r + 1)}{2}}} \qquad (1)$$

Where

C = Speed of light

f_0 = Centre frequency

ε_r =Dielectric constant of substrate *b) Patch Length* (L)

The effective dielectric constant (ε_{reff}) given in the equation as follows:

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

Due to the fringing filed the patch length is extended along its length end is given by:

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

The actual length (L) of the patch is calculated as:

$$L = \frac{\lambda_0}{2} - 2\Delta L \quad (4)$$

c) *Design of Feed Position*

The design of feed position to achieve 50Ω input impedance for impedance matching in the microstrip antenna is required to provide maximum power transfer to the antenna. The inset length or the inset feeding position on the edge of Inset Fed Microstrip patch is given by using [12].

$$Y_0 = 10^{-4}\{0.001699\varepsilon_r^7 + 0.1376\varepsilon_r^6 - 6.1783\varepsilon_r^5 + 93.187\varepsilon_r^4 - 682.69\varepsilon_r^3 + 2561.9\varepsilon_r^2 - 4043\varepsilon_r + 6697\}\frac{L}{2} \quad (5)$$

Where Yo is the desire inset distance from the edge of the patch towards the patch Centre as shown in figure 2.To match the input impedance of the patch antenna at 50Ω the value of Yo is,

Yo = 0.848mm

$$Y_f = \frac{W}{2} \quad (6)$$

d). *Ground Dimension*

The dimensions of the ground plane is calculated:

$W_g = W + 6h$ (7)

$L_g = L + 6h$ (8)

Where, W_g and L_g denotes width of the ground plane and length of the ground plane respectively.

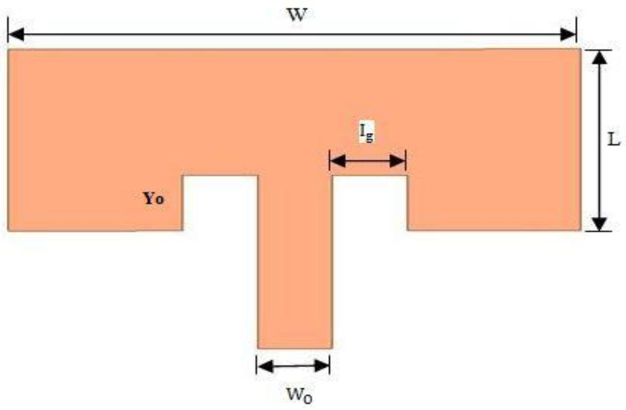


Fig.2: Patch dimension of Inset Fed Microstrip Antenna.

I. Simulations And Results

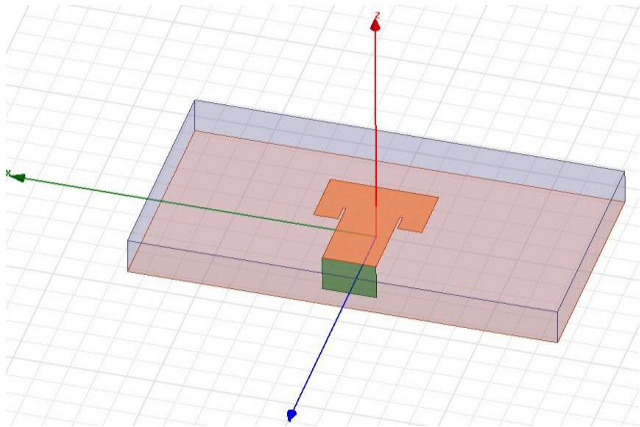


Fig.3: Design of Single Element IFMPA using HFSS 18 version.

The different parameter calculated value of a single element Inset Fed Microstrip Antenna is shown in table I using the design formula [13] to [17].

Table **I** shows the calculated values of the different parameter of a single element Inset Fed Microstrip Antenna using the design formula[13] to [17].The parametric analysis of different parameter values of the antenna using HFSS gives the optimum result of gain, return loss and VSWR are also given in Table I.

Table i. Antenna parameter

PARAMETER	Length	
	Formula (mm)	Parametric Analysis(mm)
Length of Patch, L	2.078mm	2.1mm
Width of Patch, W	3.823mm	3.83mm
Substrate thickness,h	1.6mm	1.6mm
Ground Length, Lg	11.678mm	8.39mm
Ground Width, Wg	13.423mm	15.2mm
Inset Gap, Ig	1.9mm	0.1mm
Inset Distance, Yo	0.848mm	0.641mm
Microstrip feed width Wo		1.9mm

At 31GHz the designed single element has achieved -13.52dB return loss. The return loss S_{11} is below -12dB in the frequency band 28GHz to 35 GHz shown in the graph Fig.4.

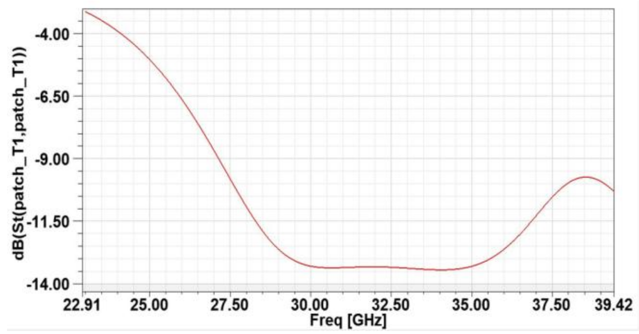


Fig.4: Return loss for 28 GHz to 35 GHz frequency band.

The voltage standing wave ratio (VSWR) of the designed antenna has achieved good results in the frequency band 28GHz-35GHz i.e. VSWR $\leq$ 1.8 (28GHz-35GHz). At the center frequency, 31GHz the designed achieved VSWR value of 1.55. Figure 5 VSWR graph shows that the designed antenna has well matched to the input impedance. The designed antenna VSWR result shows that the input port impedance is a well match.

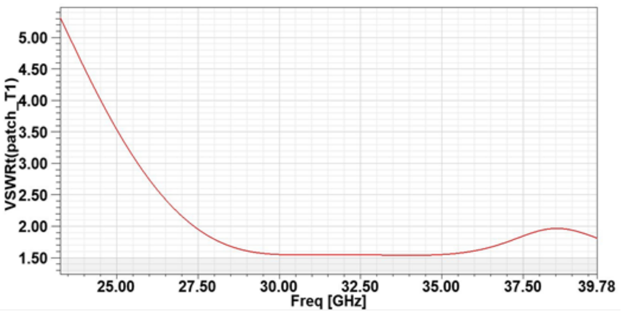


Fig.5: VSWR vs Frequency.

The 3D radiation pattern (gain) of the single element inset fed microstrip patch antenna is shown in figure 6 below. The designed has achieved a maximum gain of 6.165dB.

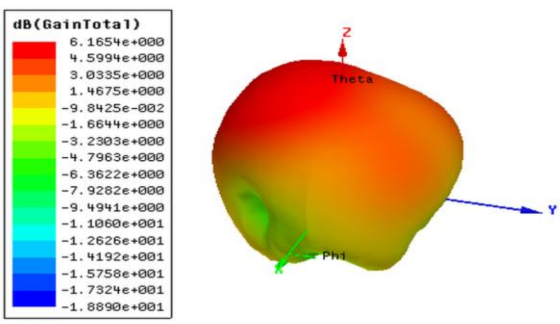


Fig.6: 3D Radiation pattern (Gain).

B. Array Design

The antenna array is designed using RT Duroid 5880 as a substrate and has a dimension of 25mm x 20mm x 1.6mm. The 4x1 circular phase array design using the HFSS18 version software is shown in Figure 7. The designed arrange the four Inset Fed Microstrip Patch Antenna on a different circular phased array using the sequential rotational feeding line, a feed line with a coplanar waveguide. Using the sequential rotational feeding line provides the unequal excitation to each antenna result to reduce the undesirable radiation i.e. side lobe radiation. Using the ring-shaped sequential rotational feeding line provides the unequal excitation to each antenna results to reduce the undesirable radiation i.e. side lobe radiation is minimized [18] to [21]. In figure 7, Z_1= 0.3mm, Z_2 = 0.6mm, Z_3 = 0.9mm and Z_4 = 1.2mm.

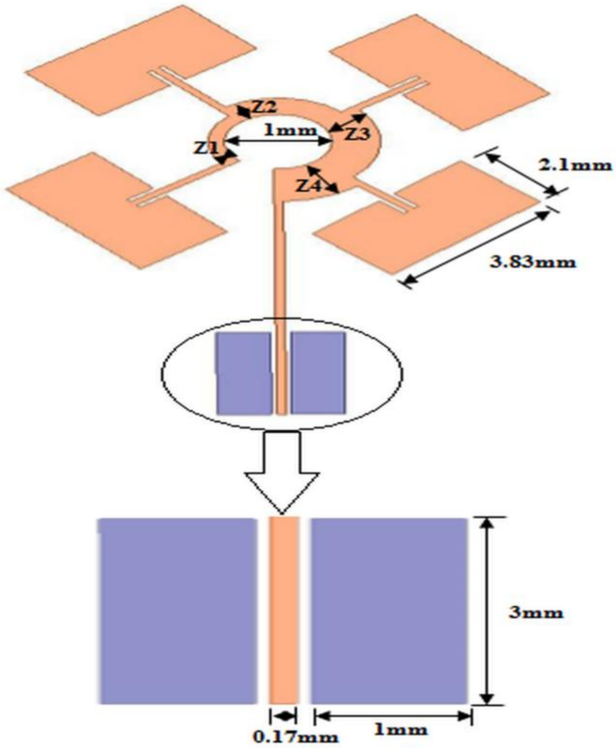


Fig.7: 4x1 circular Phase Array design using HFSS.

The design antenna array achieved good return loss -10dB $\leq$ S_{11} $\leq$ -18.64dB and maintaining 26% (24.81GHz-33GHz) bandwidth. The antenna array has achieved good return loss S_{11}, -18.64dB at 29.09GHz. Figure 8 shows the return loss S_{11} of 4x1 designed array.

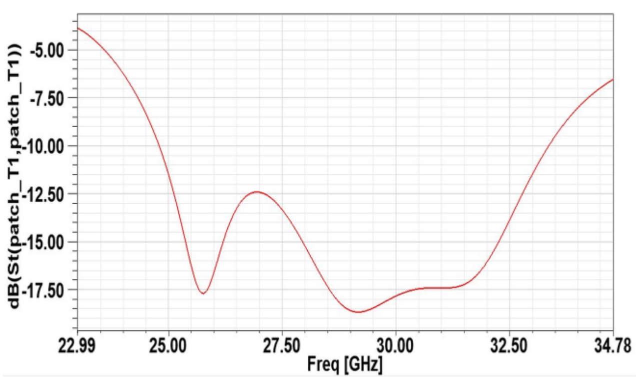


Fig.8: Return loss S11 for band (23 GHz-34GHz)

In the lower millimeter frequency the design achieved good VSWR value i.e. VSRW $\leq$ 1.85 in 24.81GHz-33GHz and the value is less than 2. So the designed antenna has a wide impedance bandwidth (VSWR < 2) of 26% (24.81GHz-33GHz).

The VSWR graph of the 4x1 circular phased array is shown in fig.9.

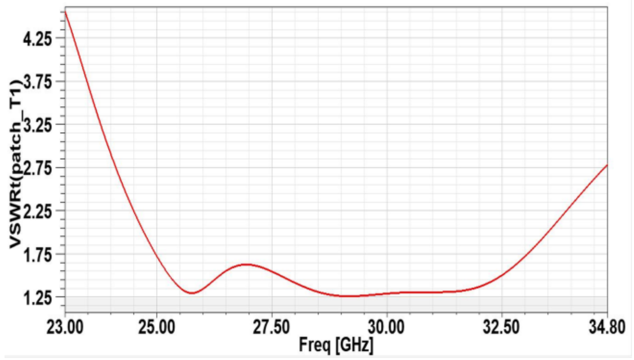


Fig.9: VSWR vs Frequency

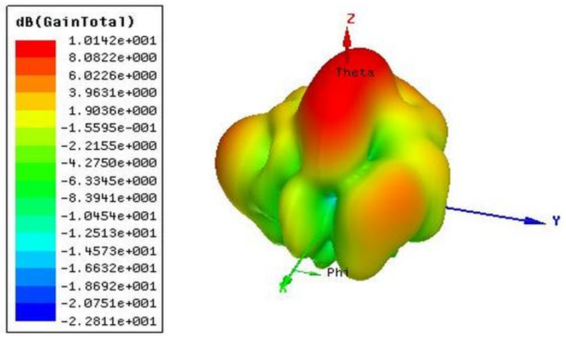
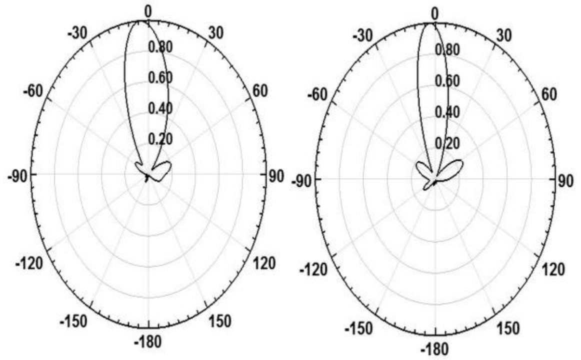
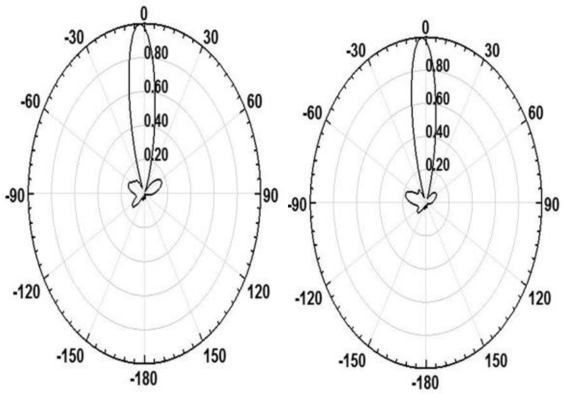


Fig.10: 3D Radiation pattern (Gain)

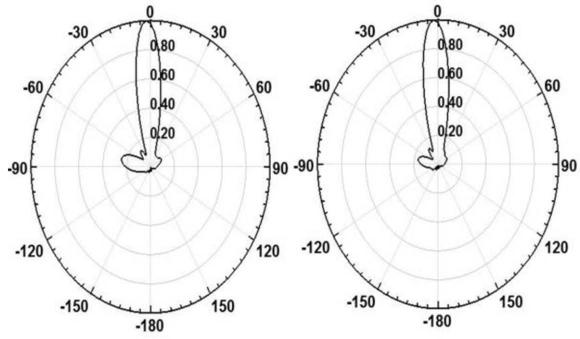
The 3D radiation pattern (gain) of the 4×1 circular phased array is shown in figure 10 above. The designed array has achieved a maximum gain of 10.14dB.



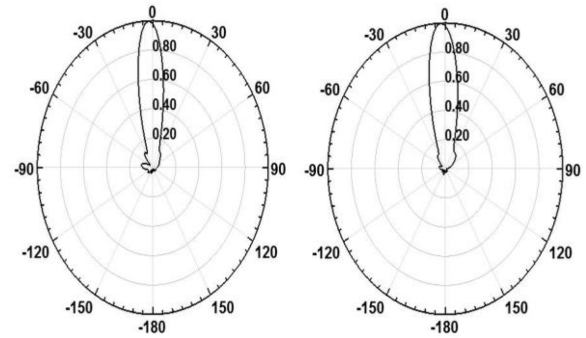
(i) **(ii)**



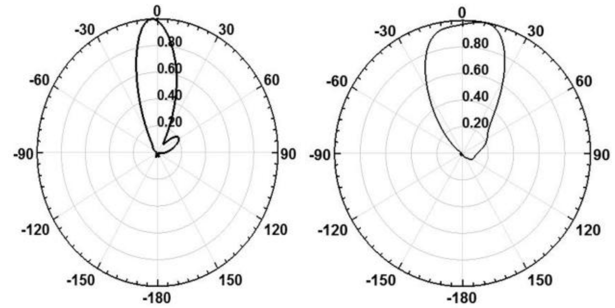
(iii) **(iv)**



(v) **(vi)**



(vii) **(viii)**



(ix) **(x)**

Fig.11: Normalized radiation patterns of designed array at 31GHz different values of ϕ (i) ϕ = 300 (ii) ϕ = 500 (iii) ϕ = 600 (iv) ϕ = 700 (v) ϕ = 1000 (vi) ϕ =1050 (vii) ϕ =1100 (viii) ϕ =1200 (ix) ϕ =1400 and (x) ϕ =1800

Table II. Result Summary

Number Of Element	Gain	Return Loss Bandwidth $S_{11} \leq -10$dB	VSWR Bandwidth VSWR < 2
Single Element	6.165dB	$-10dB \leq S_{11} \leq -13.5dB$ (28GHz– 35GHz)	VSWR ≤ 1.8 28GHz–35GHz
4x1 Element circular phase array	10.14dB	$-10dB \leq S_{11} \leq -18.64dB$ (24.8GHz-33GHz)	VSWR ≤ 1.85 24.8GHz-33GHz

III. RESULT AND DISCUSSION

The designed antenna array achieved return loss bandwidth of 26%. The antenna array has achieved good return loss S_{11},-18.64dB at 29.09GHz and VSWR ≤ 1.85 (24.81GHz-33GHz). The designed array has return loss values – 10dB ≤ $S_{11} \le$ – 18.64dB and achieved circularly polarized gain of 10.14dB. The designed array has wide bandwidth of return loss, VSWR and gain. So the designed can used for the mmWave wireless communication.

IV. CONCLUSION

In this paper, present a 4x1 circular phase array Inset fed microstrip patch antenna in the lower mmWave frequency range (24.81GHz-33GHz). To further enhance gain, metamaterial and superstrate should be used in the designed. The proposed array will be suitable for the future short range 5G mmWave wireless communication.

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