Crescent Shaped Slot Mmwave Array Antenna for Future 5g Femtocells Applications

Harini V, Sairam M V S, MadhuR, Naresh Kumar M

Abstract*: Multiband mm-wave crescent-shaped slot array antenna is designed for future femtocells applications. Initially, a single rectangular patch with dimensions 2mm X 2mm is used and crescent-shaped slot with dimensions 0.8mm outer radius and 0.6mm inner circle radius is introduced in it. A Rogers RT duriod 5880 with a dielectric constant of 2.2 and a thickness of 0.508mm is used as the substrate for designing an mm-wave single patch and an array antenna. The proposed mm-wave array antenna is radiating at multiband frequencies like 27.2GHz, 29.68GHz, 34.5GHz, 37.4GHz, and 46.8GHz and attained a gain of 9.2dB, 7.355dB, 10.13dB, 13.01dB, and 12.5dB correspondingly which is able to cover most of the 5G frequency bands. A detailed analysis is presented on performance metrics like reflection coefficient, gain, E-field distribution, radiation pattern at each and every frequency based on simulation results.

***Index Terms*: femtocells, crescent, 5G bands, multiband, mm wave array antenna.**

I. INTRODUCTION

Femtocell Access Point is a low range and RF output power base station which works up to the range of 30m in indoor communications [1]. In both licensed and unlicensed spectrum femtocells can be operated. In 5G, femtocells are going to play an important role as there is an increase in densified network capacity indoors. Miniaturized antennas play a major role in the design of Femtobase stations which leads to the design of mm-wave antennas. Performance of the femtocells depends on the efficient working of the antenna [2]. In 2019, TRAI (Telecom Regulatory Authority India) announced that they are planning for 5G services. To realize the importance of 5G, enough spectrums are made available in appropriate frequency bands. In addition to this Asia-Pacific Tele community (APT) conference preparatory group, World Radio Conference-2019 (WRC-19) conducting, sharing and compatibility studies on 24.25-27.5GHz, 31.8-33.4GHz and 37-40.5GHz bands for mm-wave communications as shown in Fig.1.

For Fixed, Mobile and Fixed Satellite System (FSS) services 28 GHz is allotted by WRC-19 along with this a new service called Earth Station in Motion (ESIM), where miniaturized terminals with satellite communication capabilities are installed on femtocells, aircrafts, ships and land vehicles [3].

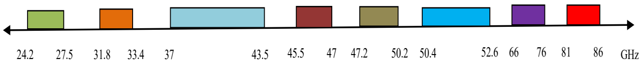

Fig. 1. 5G Frequency Bands

Crescent shape micro strip antenna with air suspension is designed which attains broadside gain of 1.5 to 5dBi across four frequencies [4].An eight shape patch antenna with crescent shape slot is proposed for UWB application in 3-6 GHz and attained gain of around 7dB with various radiuses of crescent slots [5]. Within the range of 3–10 GHz, a monopole crescent shape antenna is designed and found similar radiation properties like elliptical antenna with 40% reduction in area used in UWB applications [6]. A four dipole millimeter-wave antenna is proposed for MIMO applications at 28 GHz band and attained gain of 10dB with minimum isolation of 21dB [7]. A leaf shaped bow-tie elements of an end-fire phased array 5G antennas is designed for MIMO applications at 28 and 38GHz and has attained good radiation behavior at both of the 5G candidate bands [8]. For future 5G mobile communication, a compact elliptical antenna is designed which has the band width of 26.6-31.2 GHz and attained good resonance at 28 GHz [9].

II. ANTENNA DESIGN

A. Single patch mm-wave antenna with Crescent-shaped slot

The geometry of the proposed Crescent-shaped slot mm wave base antenna size is 2mm x 2mm patch and crescent shape is achieved by subtracting an inner circle radius of 0.6mm from outer circle radius of 0.8mm as shown in Fig.2. The antenna is designed on Rogers RT duriod 5880 substrate material with $\varepsilon_r = 2.2$ and a dielectric loss tangent of 0.0009. The thickness of the substrate h=0.02” (0.508mm) [4]. The size of substrate is 4mm x 4mm. A ground plane of width 4mm and length 4mm is considered at the bottom side. The dimensions of feed are 1.4mm x0.2mm and the feeding probe position is located at a distance of 2.5mm from the antenna edge.

Manuscript published on 30 June 2019.

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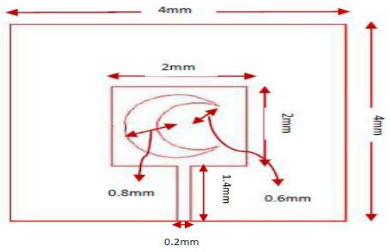

Fig. 2. Geometry of proposed crescent slot mm-wave base antenna

The fundamental design procedure of antenna is given in equations from 1 to 4 as follows

The patch antenna width

$$W_{pat} = \frac{1}{2f_{res}\sqrt{\varepsilon_0\mu_0}}\sqrt{\frac{2}{\varepsilon_{re}+1}} = \frac{c}{2f_{res}}\sqrt{\frac{2}{\varepsilon_{re}+1}} \quad (1)$$

Effective dielectric constant

$$\varepsilon_{ref} = \frac{\varepsilon_{re}+1}{2} + \frac{\varepsilon_{re}-1}{2}\left[1+\frac{12h}{W_{pat}}\right]^{-\frac{1}{2}} \quad (2)$$

The extension length

$$\frac{\Delta L}{h_s} = \frac{0.412(\varepsilon_{ref}+3)\left(\frac{W_{pat}}{h_s}+0.264\right)}{(\varepsilon_{ref}-0.258)\left(\frac{W_{pat}}{h_s}+8\right)} \quad (3)$$

Actual length of patch $L_{eff} = L + 2\Delta L$ (4)

where h_s = thickness of substrate; L = patch length;

L_{eff} =effective length.

Based on the above equations, the resonating frequency of chosen length and width of patch is 43.6GHz but as the Crescent-shaped slot is introduced in the patch , the resonating frequency is reduced to 38.9GHz.

B. Crescent-shaped slot mm-wave 1x 4 array antenna

A set of two to several thousands of antennas is called antenna array. The motivation behind why array antenna is more well known than its identical single component modeis that the coverage area can be increased without increase in total system size. The geometry of the proposed mm-wave 1x4 array antenna follows single antenna structure with the gap 4mm between the antennas.The size of the RT duriod 5880 substrate is 24mm x 5mm with 0.508mm thickness as shown in Fig.3. The feeding position is chosen such that the required bands and gain existence is occurred only when the feed is given at 9mm from the edge of the antenna.

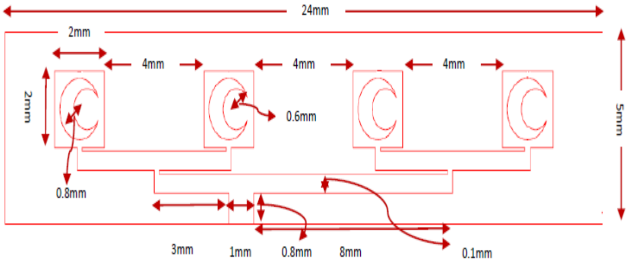

Fig. 3. Geometry of proposed crescent slots mm-wave 1x4 array antenna

The implemenation of array plan has bee checked dependent on a broad investigation to choose for beteer isolation, impedance matching , gain and resonable radiation pattern.

III. RESULTS AND DISCUSSIONS

Designing and simulation of the proposed single patch mm wave antenna and array antenna is performed using commercially available Ansoft HFSS version 15 tool. The performance of the mmwave antenna is evaluated in terms of radiation characteristics, gain, reflection coefficient (S_{11}), surface current distributions and efficiency. Voltage Standing Wave Ratio (VSWR) describes the efficient use of RF power transmitted from source. The impedance mismatch is represented by reflection coefficient at the load. The negative logarithmic value of reflection coefficient gives return loss. For the sensible applications, VSWR=2 is suitable because the return loss would be -9.54 dB or -10dB.

A. Simulation of single patch mm-wave antenna with Crescent-shaped slot

The simulations were initiated by designing a single patch with Crescent-shaped slot using the equations discussed in Section II. The basic antenna structure is designed in HFSS is as shown in Fig.4.

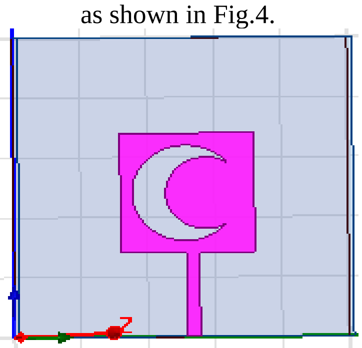

Fig. 4. Proposed crescent slot mm-wave base antenna structure in HFSS

The Reflection coefficient of proposed mm-wave basic antenna is as shown in Fig.5. The corresponding S_{11}(dB) attained at 38.9GHz is -17.2685dB.

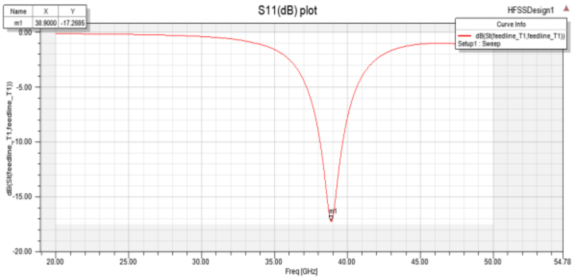

Fig. 5. **Reflection Coefficient (S_{11}dB) of proposed mm-wave base antenna**

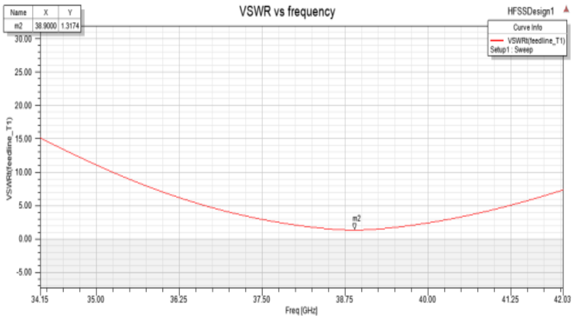

Fig. 6. **VSWR of proposed mm-wave base antenna**

The Voltage standing wave ratio(VSWR) describes the reflected power from the antenna. The smaller the VSWR is the better the antenna is matched to the transmission line means more power delivered to the antenna. Ideally VSWR is 1 but practically it can be upto 2 for microstrip antenna.At 38.9GHz the VSWR value is 1.317 for mm-wave base antenna as shown in Fig.6.

The simulated 3D polar plot and azimuth, elevation patterns for the designed antenna at the resonant frequency 38.9GHz are illustrated in Fig.7 and Fig.8. The gain achieved at 38.9GHz is 7.627dB. It is observed from the figures that the radiation patterns are stable at the resonant band and are almost produce directional pattern.

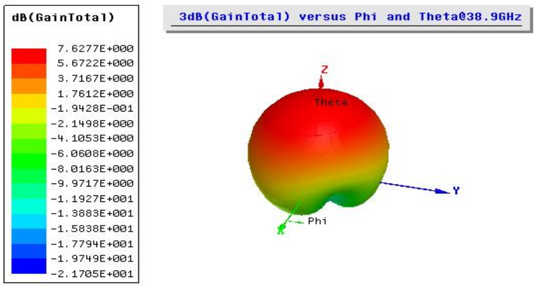

Fig. 7. 3D polar plot @38.9GHz of proposed mm-wave base antenna

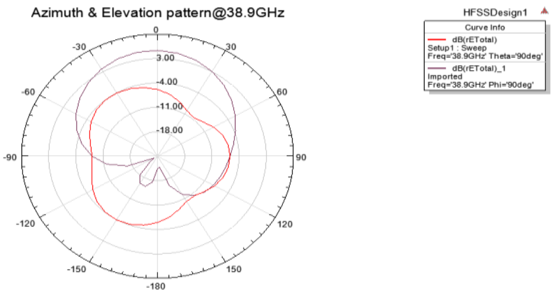

Fig. 8. Azimuth & Elevation pattern @38.9GHz of proposed mm-wave base antenna

The Electric field distributions of the proposed mm-wave base antenna are mainly contributed by feed line at resonating frequency 38.9GHzas shown in Fig.9

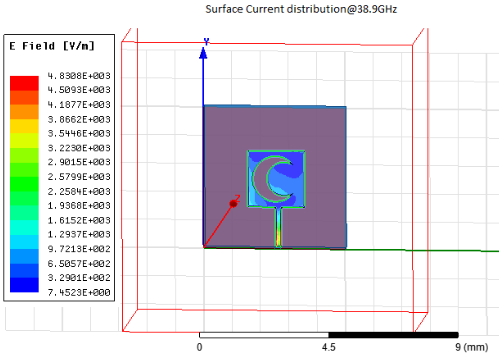

Fig. 9. Surface current distribution@38.9GHz of proposed mm-wave base antenna.

B. *Simulation of mm-wave 1x4 array antenna with Crescent-shaped slot*

The proposed Crescent-shaped slot mm wave 1X4 antenna structure is designed in HFSS is as shown in Fig.10. The initial dimensions for dual linear polarization are the same asthe single polarization element. The patch and feed dimensions were maintained from single patch dimensions while designing 1x4 arrays antenna.

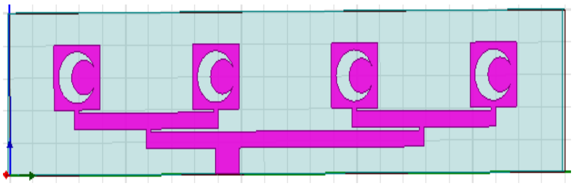

Fig. 10. Proposed crescent slot mm-wave 1x4 array antenna structure in HFSS

The simulated return loss of 1X4 micro strip mm wave array antenna is as shown in Fig.11.The corresponding S_{11}(dB) attained at multiple frequencies like 27.2GHz, 29.68GHz, 34.5GHz, 37.4GHz and 46.8GHz are -12.3dB, -16.88dB, -11.06dB, -20.25dB and 30.92dB.

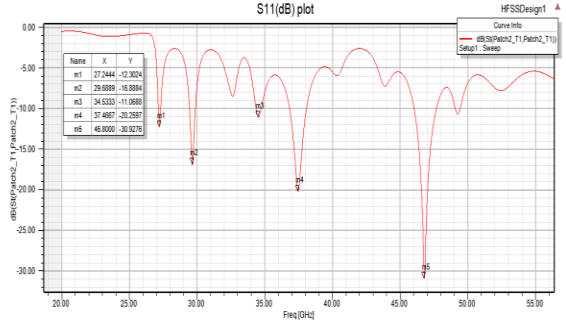

Fig. 11. Reflection Coefficient (S_{11}dB) of proposed mm-wave array antenna

The VSWR values at 27.2GHz, 29.68GHz, 34.5GHz, 37.4GHz and 46.8GHz are 1.64,1.33,1.77,1.21 nad 1.068 for proposed mm-wave1X4 microstrip mm-wave array antenna as shown in Fig.12.

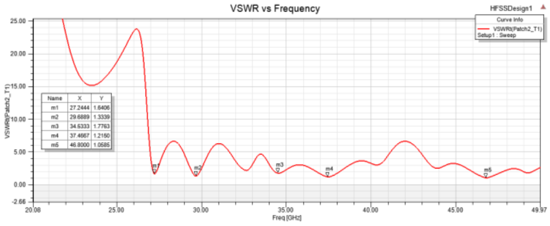

Fig. 12. VSWR of proposed mm-wave array antenna

The simulated 3D polar plot for the designed antenna at the resonant frequency 27.2GHz are illustrated in Fig.13 and attained gain of 9.2dB.

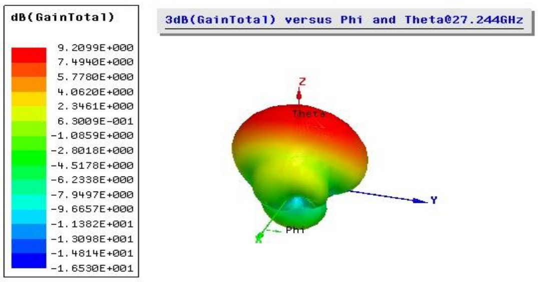

Fig. 13. **3D polar plot @27.244GHz of proposed mm-wave array antenna**

The simulated radiation patterns in azimuth (xy plane) and elevation (yz plane) cuts for resonating frequency 27.2GHz is as shown in Fig.14 and corresponding current distribution is mainly at the feeding network as shown in Fig.15.

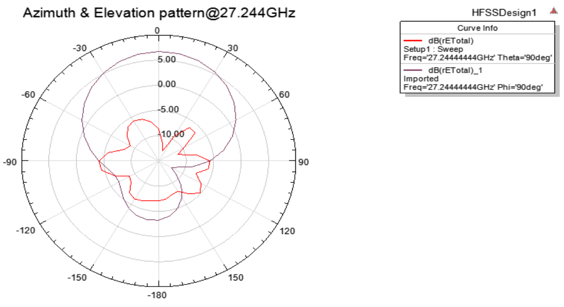

Fig. 14. Azimuth & Elevation pattern @27.244GHz of proposed mm-wave array antenna

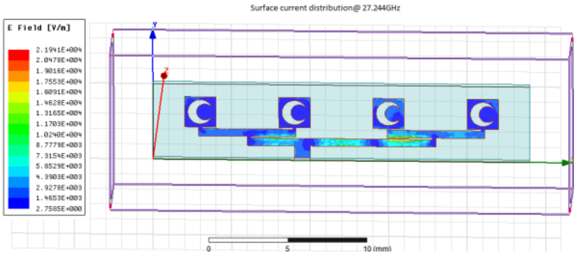

Fig. 15. Surface current distribution@27.244GHz of proposed mm-wave array antenna

The simulated 3D polar plot for the designed mmwavae 1X4 array antenna at the resonant frequency 29.6GHz are illustrated in Fig. 16 and attained gain of 7.35dB.

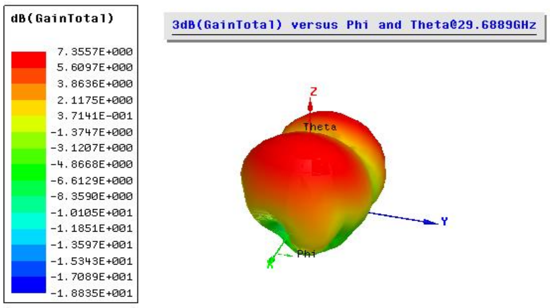

Fig. 16. 3D polar plot @29.6889GHz of proposed mm-wave array antenna

The simulated azimuth (xy plane) and elevation (yz plane) cuts for resonating frequency 29.68GHz is as shown in Fig.17 and corresponding current distribution is mainly at the 1st division feeding network as shown in Fig.18.

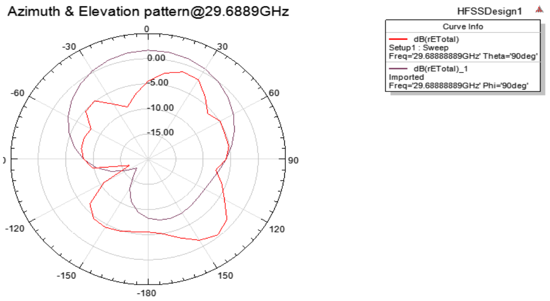

Fig. 17. Azimuth & Elevation pattern @29.6889GHz of proposed mm-wave array antenna

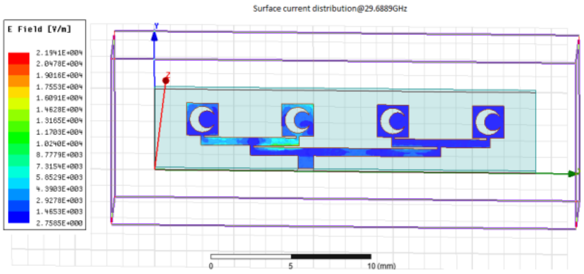

Fig. 18. Surface current distribution @29.6889GHz of proposed mm-wave array antenna

The simulated 3D polar plot for the designed mm wave 1X4 array antenna at the resonant frequency 34.53GHz as shown in Fig.19 and attained gain of 10.13dB.The simulated azimuth (xy plane) and elevation (yz plane) patterns at resonating frequency 34.53GHz is as shown in Fig.20 and corresponding current distribution is mainly at the 1st division feeding network and 1st patch is as shown in Fig.21.

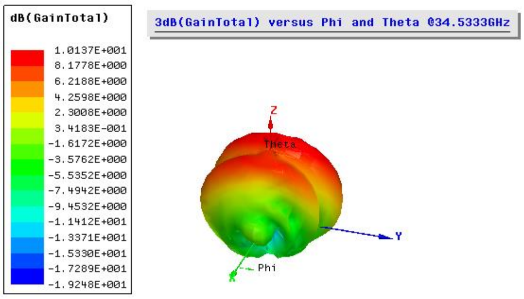

Fig. 19. 3D polar plot @34.5335GHz of proposed mm-wave array antenna

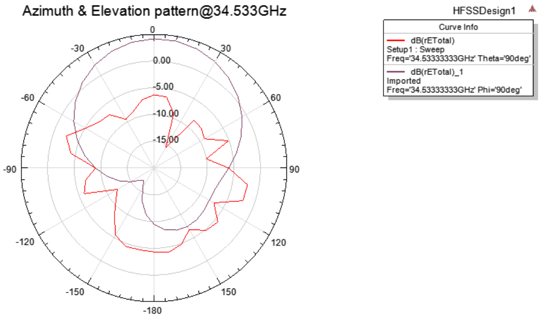

Fig. 20. Azimuth & Elevation pattern @34.533GHz of proposed mm-wave array antenna

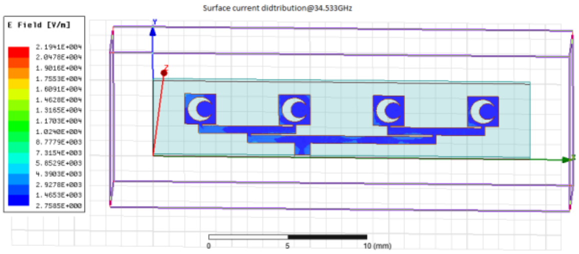

Fig. 21. Surface current distribution@34.533GHz of proposed mm-wave array antenna

The simulated 3D polar plot for the designed mm wave 1X4 array antenna at the resonant frequency 37.466GHz with gain of 13dB as shown in Fig.22.

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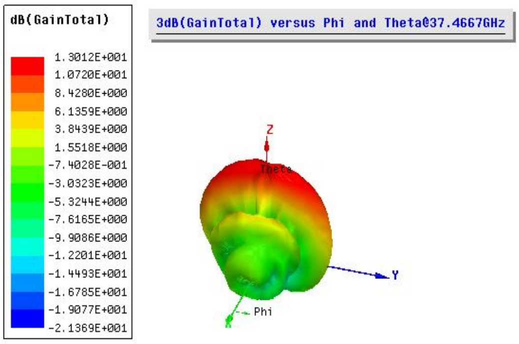

Fig. 22. 3D polar plot @37.4667GHz of proposed mm-wave array antenna

The simulated azimuth and elevation patterns at resonating frequency 37.4GHz is as shown in Fig.23 and corresponding current distribution is not having much impact on patch which is shown in Fig.24.

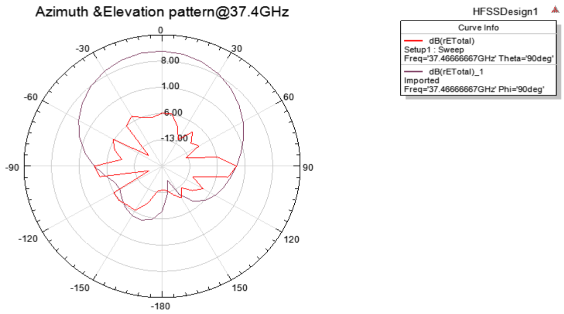

Fig. 23. Azimuth & Elevation pattern @37.4GHz of proposed mm-wave array antenna

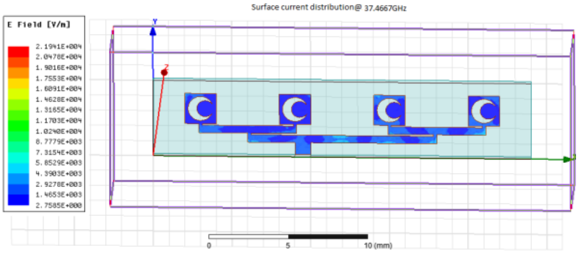

Fig. 24. Surface current distribution@37.4GHz of proposed mm-wave array antenna

The simulated 3D polar plot for the designed mm wave 1X4 array antenna at the resonant frequency 46.8GHz attains gain of 12.5dB as shown in Fig.25.

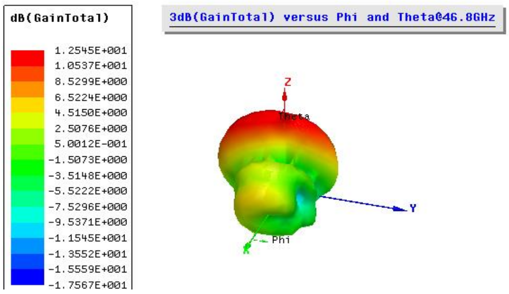

Fig. 25. 3D polar plot @46.8GHz of proposed mm-wave array antenna

The simulated azimuth and elevation patterns at resonating frequency 46.8GHz is as shown in Fig.26 and corresponding current distribution is not having much impact on patch which is shown in Fig.27

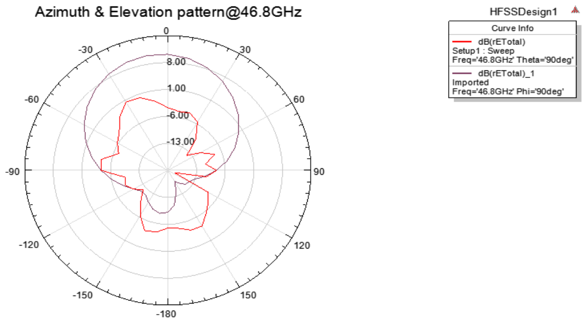

Fig. 26. Azimuth & Elevation pattern @46.8GHz of proposed mm-wave array antenna

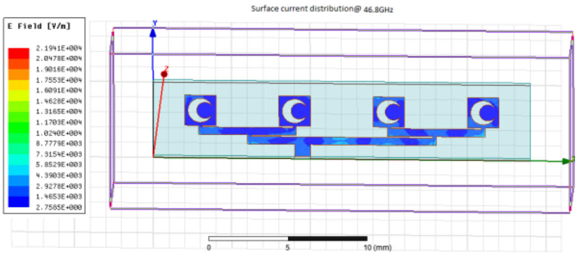

Fig. 27. Surface current distribution@46.8GHz of proposed mm-wave array antenna

The accompanying Table.1 depicts the total readings of mm wave antenna and array antenna of different parameters like gains, directivity, and efficiency at various resonating frequencies.

TABLE I. PROPOSED ANTENNA READINGS

S.No	**mmwave base antenna**			
	Frequency (GHz)	***Gain (dB)***	***Efficiency (%)***	***Directivity(dB)***
1.	38.9	7.627	102.3	7.528
S.No	**Multiband mm wave array antenna**			
	Frequency (GHz)	***Gain (dB)***	***Efficiency (%)***	***Directivity(dB)***
2.	27.2444	9.2	97.59	9.315
3.	29.6889	7.355	97.80	7.452
4.	34.5333	10.136	98.55	10.179
5.	37.4667	13.01	101.46	12.94
6.	46.8	12.544	103.70	12.386

IV CONCLUSION

The proposed mm wave array is designed and analyzed using HFSS simulator. The major improvement was with resonating frequencies increased from single band to multiband antenna with acceptable reflection coefficients. The gain is also considerably increased from single patch to array antenna as discussed in Section III. The Elevated radiation pattern of proposed antenna describes a directional pattern having high peak gain at a particular direction. Directionality leads to reduction in interference in femtocell networks. Sensible performance, easy configuration and low

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profile create this antenna significantly enticing for transportable furthermore as fastened communication devices, together with femtocell access point which has same characteristics of normal base station which is used in mobile communications

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