IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 7.105 ※ Vol. 9, Issue 3, March 2022

DOI: 10.17148/IARJSET.2022.9339

Beamforming of 4x4 Millimeter-Wave Patch Array Antenna for 5G Communication Systems

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Abstract: Smartphones are becoming extremely popular due to increasing demand for higher data traffic of mobile network. This drastic increase can be related to the population explosion. It has caused rapid development in telecommunication sector to improve performances of the radio signal transmission. In Bhutan, fifth generation (5G) communication was launched in 2021 but it has not been deployed in all region of the country. The ongoing pandemic has made us realize the impact of better connectivity through technology. There are still some challenges of 4G like spectrum crisis and high energy consumption. 5G Communication can provide high-speed data transmission with methods of millimeter-wave (mm-Wave) communication, miniaturization and multi-cell array antennas but antenna design is a challenge. Integrating multiple-input multiple-output (MIMO) technology into smartphone antenna can effectively increase the performance of spectrum efficiency and channel capacity. A 4x4 Dual band mm-Wave slotted patch array antenna for the 5G communication is proposed in this paper and the beam-forming will be performed. The proposed antenna is operating at LTE bands 30-40 GHz. The antenna can be used in mobile phones as well as in Base stations. The bandwidth, gain, directivity, reflection coefficient and VSWR will be studied for the antenna to meet the future 5G capabilities.

Keywords - 5G Communication, Millimeter wave, MIMO, Patch antenna, Beam-forming.

I. INTRODUCTION

Wireless communication has undergone huge development in order to support the demand of high data traffic due to the exponential increase of smartphones [1]. Increasing usage of web, entertainment, streaming, and gaming, has incurred the need of high-speed internet and capacity of wireless networks. According to Statista, there are 7.1 billion mobile users in 2021 and it is expected to reach 7.49 billion by 2025 [2]. There are 4.32 billion mobile internet users in 2021 [3]. 4G Communication might not able to handle the explosive increasing demand of data usage due to low latency, speed, capacity and reliability. 5G technology has got some latest mobile technologies which further enhances the capabilities to provide multi-Gbps data rates and infinite data broadcast. Usage of unlicensed bandwidth beyond the licensed band in the mm-Wave communication, has highly given attention in 5G mobile communication systems [4-6]. The transmitter and receiver location need to be in Line-of-Sight (LOS) range because wavelength of mm-W band is very short [7]. So, the surrounding obstacles like trees and buildings will affect the performance of mm-W cellular communication. In order to solve this problem, 5G will have heterogeneous network where microcells will cover larger region [8]. Dual band milli-meter patch array antenna was designed for 5G Communication in [9].
The proposed antenna is operating at LTE bands 30-40 GHz which is the mm-W range. This is Extremely High Frequency band (EHF) unlike the commonly used 5G band of Ultra-High Frequency (UHF) and Super High Frequency (SHF). Light weight antennas are usually used in mobile devices. The antenna size reduces with the increase in frequency. For better connectivity, high gain antenna is preferred with beam steering capability is desirable. Array of antenna would enable multiple beams to be formed and steered at different angles. The proposed antenna provides these characteristics [10].

II. BEAMFORMING PATCH ANTENNA

Beamforming can be achieved by phase shifting the input signal on all elements. By using appropriate beamforming techniques, the path loss can be controlled by directing the radio signal to a specific receiver which results in higher reliability and capacity in certain region. Though, mm-W signals are affected easily by attenuation, they are capable to provide data rates upto Gbps in mm-W bands [8, 11-12]. Beamforming and MIMO techniques are deployed to tackle interference and multipath effect, whereby multiple radio signal paths can be created between transmitter and receiver with array of antennas [13]. Interference can be mitigated with employment of highly directive antennas in additional to latest technologies such as high gain element, CMOS technology and antenna arrays [7, 14-16].
Microstrip patch antennas are preferred due to its lightweight, antenna miniaturization, dual frequency operation, easy beam scanning, low profile, high gain and easy to use in the array [17]. The assembly of group of small antennas which are linked together functions as a single antenna and makes the fabrication simpler. The array design can improve the

IARJSET

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DOI: 10.17148/IARJSET.2022.9339

antenna gain and directivity [15-16, 18-20]. The paper focuses on the antenna design and beamforming technique for 4x4 patch array antenna that are applicable for MIMO and mm-W communication systems.

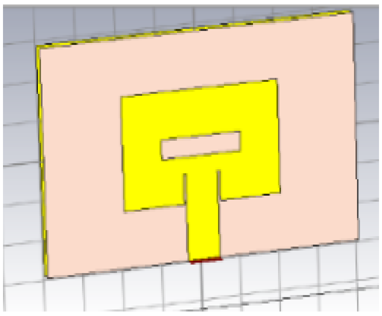

Fig. 1: Microstrip antenna with slot

III. METHODS AND DESIGN

Corporate Feeding technique is used in the antenna which is the widely and most common feeding technique for fabricating antenna arrays. It is the type of feeding technique where incident power is divided and distributed evenly to the individual antenna elements [1]. f_o is the operating frequency, z_i is the input impedance and t is the thickness of conductive patch. Duroid was used to simulate and construct the substrate which has a dielectric constant ε_r of 2.2. To calculate the dimensions of patch antenna, following equations were used [1, 18]:

Width of the patch:

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

Effective dielectric constant of the substrate:

$$\varepsilon ff = \frac{\varepsilon r + 1}{2} + \frac{\varepsilon r - 1}{2}\left[\frac{1}{\sqrt{1 + 12\left(\frac{h}{w}\right)}}\right] \tag{2}$$

Actual length of the patch:

$$L = \frac{c}{2f_o\sqrt{\varepsilon ff}} - 0.824h\left[\frac{(\varepsilon_{eff+0.3})\left(\frac{W}{h} + 0.286\right)}{(\varepsilon_{ff-0.258})\left(\frac{W}{h} + 0.8\right)}\right] \tag{3}$$

Height of substrate:

$$H_s = \frac{0.3c}{2\pi\sqrt{\varepsilon_r}f_o} \tag{4}$$

Length of Feed Line:

$$L_f = \frac{\lambda_o}{4\sqrt{\varepsilon_r}} \tag{5}$$

Width of micro strip feedline:

$$w_f = \frac{7.98h}{e^{\left(z_i\frac{\sqrt{\varepsilon r+1.41}}{87}\right)}} - 1.25t \tag{6}$$

Table 1: Simulation dimensions of the patch antenna.

SI. NO	Parameter	Values (mm)
1	Length of the ground	5.774
2	Width of the ground	7.942
3	Width of patch	3.971
4	Length of patch	2.887

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5	Height of substrate	0.251
6	Gap	0.05
7	Length of feedline	1.532
8	Width of feedline	0.816
9	Width of slot	2
10	Length of slot	0.5

All the dimensions of the patch are given in Table 1. The construction started with a simple microstrip antenna and the rectangular slot was added on the patch as shown in Figure 1. Slot was created on the patch to further enhance the performance of the antenna [21-22]. 2x2 antenna patch array was built to further increase directivity and gain. The design was further increased to 2x2 antenna array whose dimensions is given in Figure 2. It was extended to 4x4 to make it 5G capable [17]. Four ports were used on 4x4 array to make beam-steering possible as shown in Figure 3.

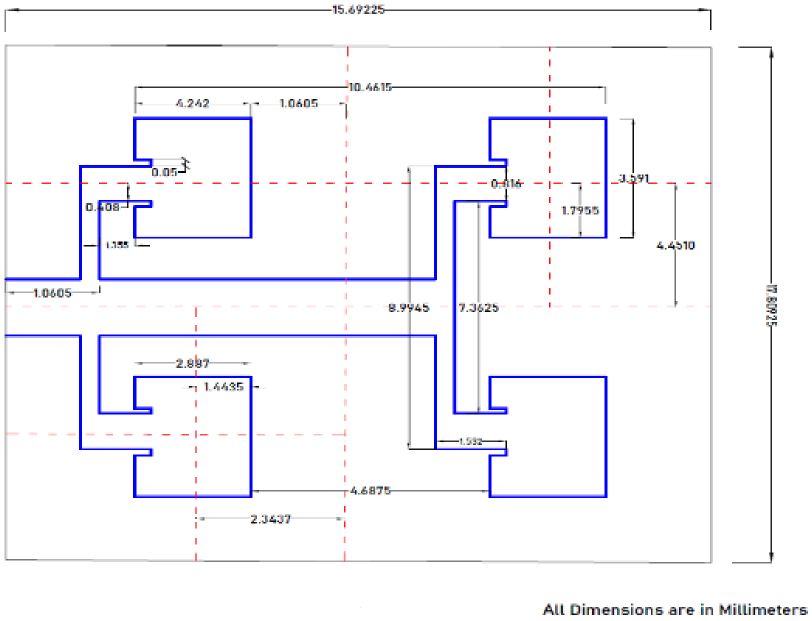

Fig. 2: Dimension of 2X2 antenna array

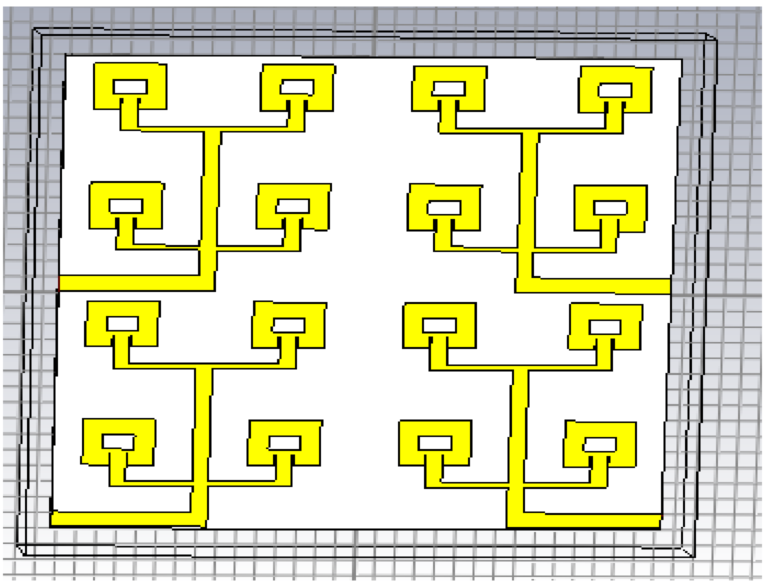

Fig. 3: 4X4 MIMO antenna array design

IARJSET

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IV. RESULTS AND DISCUSSION

Figure 4 shows the S11, S22, S33 and S44 parameters plot which gives the return loss -14.5 dB of Port 1, -10dB of Port 2, -28.5dB of Port 3 and -29.7dB of Port 4 at 33GHz respectively. Port 1 has the lowest return loss. This is true since the half-power beamwidth of the radiation from Port 1 is low which means that the directivity is high. Port 4 has the lowest directivity. Port 4 has the highest gain since it has a circular radiation pattern whereas the radiation pattern of Port 1 and 2 is more directional. It shows that when there are multiple ports, there is a chance of generation of different types of radiation patterns. The bandwidth obtained from Port 1 is 0.3 GHz and that of Port 2 is 0.05 GHz which are calculated from S11 and S22 plot.

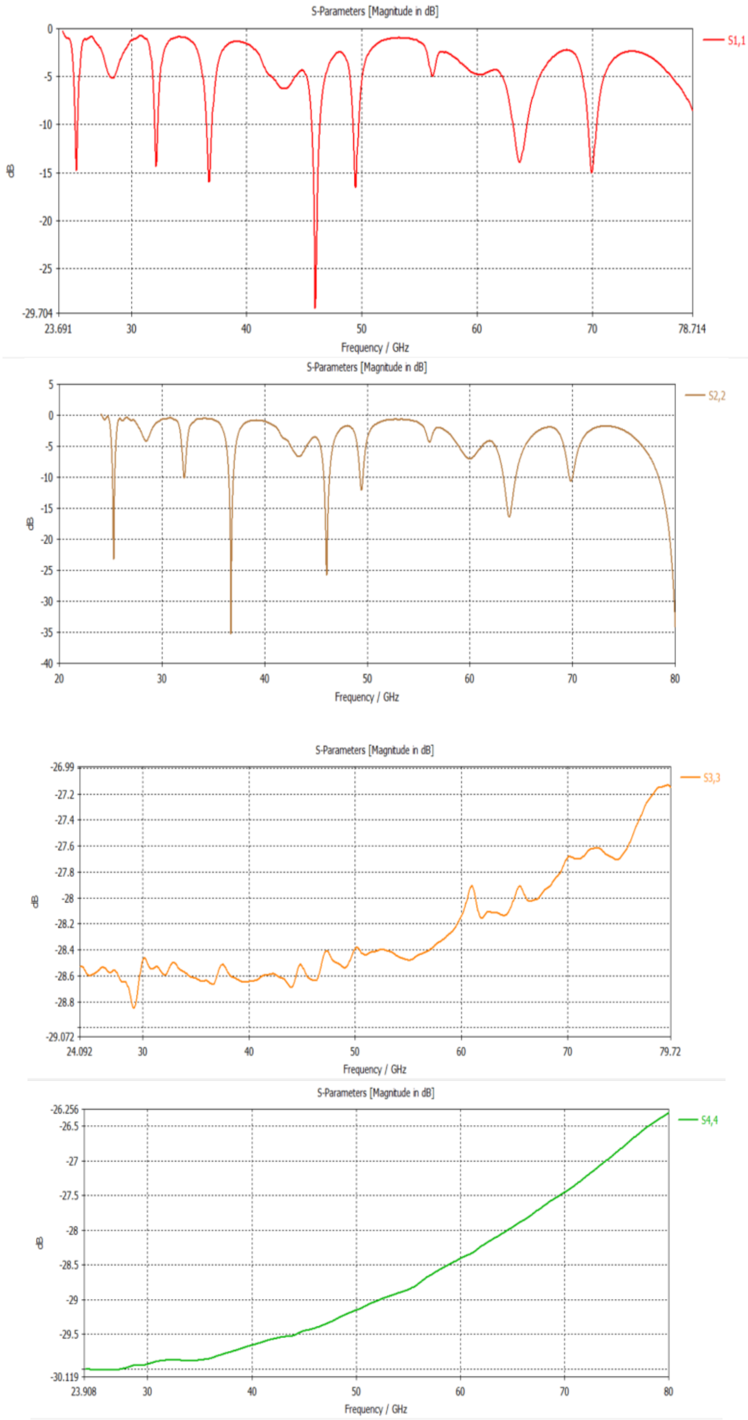

Fig. 4: S11, S22, S33 and S44 plot which shows the return loss

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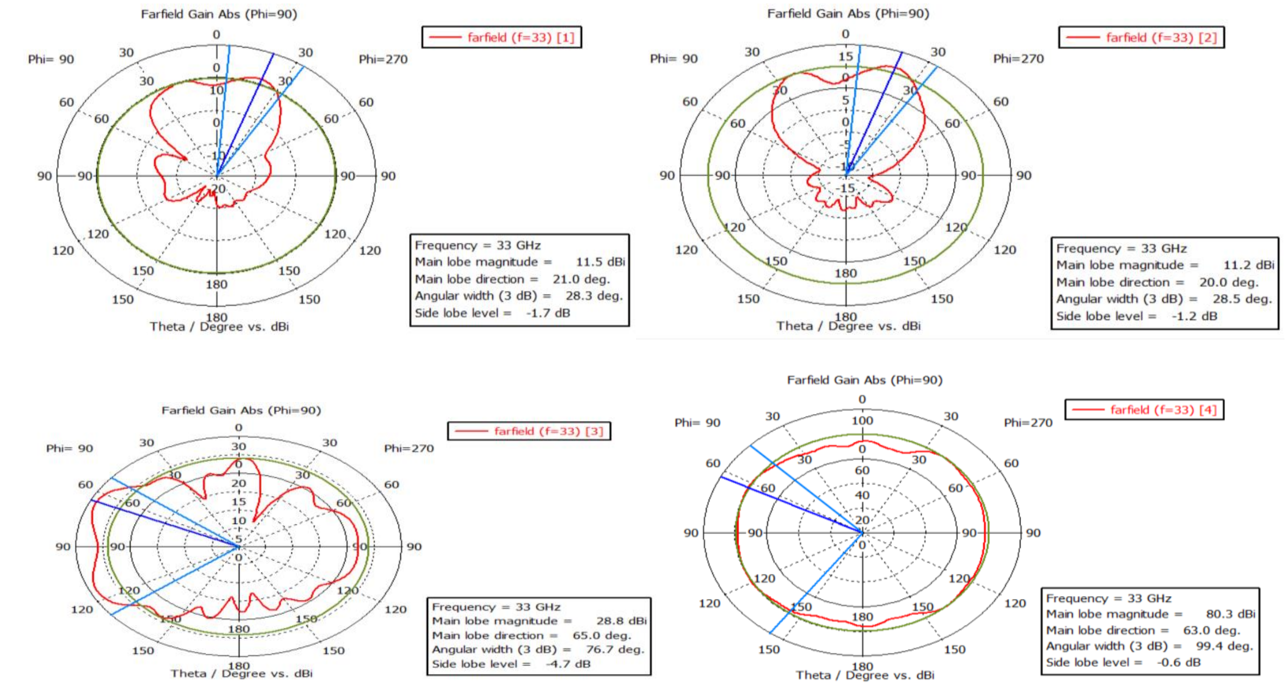

Fig. 5: Polar Radiation pattern of 4x4 4-port array antenna

There is change of main lobe direction for 4 Ports as shown in Figure 5. Port 1 and Port 2 is directed towards 21^0 and 20^0. Port 3 and Port 4 is directed towards 65^0 and 63^0. It shows that by changing the position of the Ports, the direction in which the radiation allignment can be controlled. The radiation beam is steered in four different directions using single array of antenna.

Table 2: Gain, Directivity, Direction and Returned loss of designed antenna

4x4 patch array antenna	**Gain(dBi)**	**Directivity (dBi)**	**Main lobe direction (degree)**	**Half-Power Beamwidth (degree)**	**Return loss (dB)**
Port 1	11.5	11.9	21	28.3	-14.5
Port 2	11.2	11.9	20	28.5	-10
Port 3	28.8	5.77	65	76.7	-28.5
Port 4	80.3	3.8	63	99.4	-29.7

V. CONCLUSION

The patch array antenna which is simulated in this paper is to meet the criteria of 5G communication. The compact 5G antenna has been designed, that can be used in mobile stations and base stations. The proposed antenna communicates in 5G frequency with its beamforming capabilities. In this rapidly advancing field, the antenna would definitely help in the development towards 6G communication. The consumers are demanding towards faster browsing and connectivity for which the heterogeneous coverage and mm-Wave band is required. Many 5G techniques were implemented to this antenna such as mm-Wave requirement and antenna array. Beamforming further enhances the performance of the 5G antenna. Challenges would be there to tackle the harmful radiation when operated at that high frequency. That can be explored with various uses of filter and mechanisms. Since the antenna array has 16 antennas, it is capable of MIMO communication with 4x4 Multicell matrix on which further study can be done. The designed antenna can be further extended for massive MIMO purposes to 6x6 or 8x8 array.

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IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

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