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DESIGN AND SIMULATION OF DUAL BAND mmWAVE PATCH ARRAY ANTENNA FOR 5G COMMUNICATION SYSTEMS

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Abstract— Currently, the smartphones are gaining more and more popularity, due to their increasing demand for higher bandwidth and higher data rates. The exponential growth of the population has caused telecommunication sector to meet the requirements to achieve multiband operation and improve the radio signal transmission performances. In Bhutan, 5G is expected to launch from 2022. The ongoing pandemic has made us realize the impact of better connectivity through technology. There are still some challenges that cannot be accommodated even by 4G, such as the spectrum crisis and high energy consumption. Miniaturization and multi-cell array antennas in 5G offer the possibility of high-speed data transmission but pose challenges for cell phone antenna designs.

As, it has been known that multiple-input multiple-output (MIMO) operation can effectively increase the spectrum efficiency or channel capacity, thus, the applying of MIMO technology into a smartphone will ensure the enhancement of its channel capacity. A Dual band mm Wave slotted patch array antenna for the 5G communication is proposed in this paper. The proposed antenna is operating at LTE bands 24-30GHz and 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 5G capabilities.

Keywords—5G, MIMO, Patch antenna, Array antenna, Dual band, mm Wave, beam steering.

I. INTRODUCTION

In the last few decades, economic and social development is greatly influenced by the advancement in the field of mobile communication. Having gone through the four major wireless evolution that are 1G, 2G, 3G and current generation 4G wireless mobile communication. But due to increase in demand services and increase in data usage to provides efficient system capacity, it lets to evolution of new mobile communication and elimination of antennas for mobile phone in the 1990s. Even though the current 4G wireless cellular system provide sufficient services, however there are concern about whether the current 4G will be able to sustain the increasing demand in data usage after few years. The current 4G provide services in the speed of 10Gbps and some drawback of the present cellular system include low latency, speed, capacity, battery consumption and reliability. Therefore, it lets to development of the fifth-generation cellular system popularly known as 5G. [1-2,6]

For the cellular system, different antennas are used for wireless cellular communication such as micro-strip patch antenna, slot antenna and more over array of antenna is used in 5G for transmitting and receiving information for MIMO technology [7]. MIMO technology gives the strong relative impact to 5G wireless communication system due to its benefits in terms of performance improvements with respect to Omni-directional antennas. The reason behind using these antennas array for 5G communication is that 5G operate in the band of millimeter wave, which is between the frequency range of 24 to 300GHz with a frequency band width of 250MHz. So, due to the high frequency the antenna size should be small and it is also mostly applicable in the devices such as smartphone [11]. The array of antenna can be in various size and usually it operates in very high frequency as compare to the other antenna. Due to introduction of the MIMO array antenna in 5G communication, the principle of diversity plays an important role in tackling the multi-path effect, low latency, high speed data rates and so on. Diversity means introduction of the multiple links in wireless communication.

In the contest of 5G communication mostly in the smartphone, matrix of array of antenna are used to create the multiple paths between the transmitter and receiver. These features of 5G antenna mainly miniaturization, multi –cell matrix array antenna and the beam steering technology is used in the 5G communication, where it is achieved by changing the phase of the input signal on all radiating elements. Phase shifting allows the signal to be targeted at a specific receiver which results in increase in speed, latency reduction, higher reliability, capacity and flexibility of the system [5].

As smartphone and other mobile communication devices continue to become more ergonomic and multifunctional, antenna miniaturization for 5G at millimeter wave is very important for maximizing the MIMO channel capacity. Therefore, to design the 5G mm wave antenna, some of the parameters that should be studied are size of antenna, types of substrate, antenna integration, feeding technique and compatibility with the existing 5G technology. However, to do implementation at device level it gives additional complexity and uncertainties at first stage of development, but we have to design an antenna for 5G wireless where we will be establishing the coherent for replicable placement to minimize antenna certainties and also other parameter such as mobile phone design material must also be considered [14]. It is also important to consider the ground plane dimension of the phone, frequency, wavelength, distance between the antennas and antenna miniaturization technique to support multi-resonant antenna design to flexibly accommodate ongoing 5G evolution across different region [8]. So, this project aimed to provide comprehensive and holistic study in designing of 5G mm wave antenna which is applicable for the smart phone application.

II. MICROSTRIP ANTENNA AND ITS ARRAY

2.1. Microstrip antenna

A Microstrip patch antenna, in its most basic form, consists of a radiating patch built on a dielectric substrate with the substrate attached to the ground plane as shown in Figure1. It is a low-profile antenna with a variety of advantages over other antennas, including being lightweight, low-cost, and having more gain. The patch is usually made of conductive metals like copper or gold and can be made into any shape. In this paper the proposed slotted patch antenna is of rectangular shape. The patch is made of copper. The patch antenna's size and operating frequency are inversely proportional. This feature boosted its popularity, especially in 5G wireless communication applications where the frequency bands are extremely wide (in Giga Hertz). As a result, the antenna is of a modest scale (in millimeter). The rectangular slot is created on the patch to increase gain and directivity. The dual band can also be created by using slotted patch antenna.

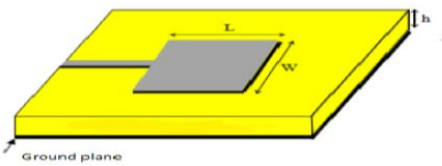

Figure 1: Simple patch antenna

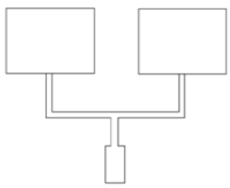

Figure 2: Cooperate feeding technique.

2.2. Array of antenna

Single-element antennas have a broad range of radiation patterns. This indicates that they have a poor directivity. Increase in the size of the single-element antenna can improve directivity. The assembly of radiating components in a suitable electrical and geometrical arrangement to form an antenna array which is another way to improve directivity. An antenna array is a group of single-antenna components that are linked together and function as a single antenna. The antenna gain and directivity are two important factors to consider. By joining the elements of antenna array, fabrication is simpler. Antenna arrays come in a variety of shapes and sizes, depending on the application [13]. In this paper, the proposed antenna is 2x2 slotted patch array antenna.

III.ANTENNA FEEDING TECHNIQUE

Different feeding strategies are used in the patch antenna array's delivery feeding network. There are a variety of methods for feeding the microstrip antenna. Such as contacting and non-contacting approaches. The contacting group denotes direct interaction between the feed line and the radiating patch [14]. In these proposed papers the feed technique used is Corporate Feeding which is the widely and most common feeding technique for fabricating antenna arrays is a corporate feed. It is the type of feeding technique where incident power is divided and distributed evenly to the individual antenna elements as shown in Figure 2.

IV. DESIGN PARAMETERS AND CONSIDERATION

Duroid was used to construct the substrate which has a dielectric constant ε_r of 2.2. f_o is the operating frequency, z_i is the input impedance and t is the thickness of patch. To calculate the dimensions of patch antenna, following equations were used:

Width of the patch:

$$W = \frac{c}{2f_o\sqrt{\frac{\varepsilon_r+1}{2}}} \quad (1)$$

Effective dielectric constant of the substrate:

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

Actual length of the patch:

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

Height of substrate:

$$H_s = \frac{0.3c}{2\pi\sqrt{\varepsilon_r}f_o} \quad (4)$$

Length of Feed Line:

$$\lambda_o = \frac{c}{f_o} \quad (5)$$

$$L_f = \frac{\lambda_o}{4\sqrt{\varepsilon_r}} \quad (6)$$

Width of micro strip feedline:

$$w_f = \frac{7.98h}{e^{\left(z_i \frac{\sqrt{\varepsilon r + 1.41}}{87}\right)}} - 1.25t \quad (7)$$

4.1. Case study

A comparative study was done by changing the dimension of the slot since it is the one of the important design parameters in antenna which increases the overall performance characteristics of the antenna. In this paper, we took dimension of the slot as 2mm x 0.5mm as it has reasonable performance in terms of its returns loss and directivity as compared to another dimension of the slot as seen in Table 1.

Table 1: Effect changing dimension of the slot.

Sl. no	Size(mm) Width x length	Gain(dB)	Return loss(dB)	Directivity(dB)	Bandwidth (GHz)
1	1.5x0.5	7.12	-15.671	7.09	2.865
2	2x0.5	6.94	-17.426	7.24	3.105
3	3x1	6.25	-22	6.25	3.925
4	4x1.2	7.65	-18.759	5.96	4.37

The comparative analysis in terms of bandwidth, directivity, return loss, VSWR and gain was done by changing the thickness of the substrate using Roger RT Duroid. From the analysis shown in Table 2, we can conclude that increase in frequency reduces the size of the patch and thickness of the substrate. With decrease in height of substrate, directivity tend to increase but return loss tend to increase.

Table 2: Changing height of the substrate

Sl.no	Frequency (GHz)	Size of patch (mm) (L x W)	Height of Substrate (mm)	Bandwidth (GHz)	Directivity (dB)	Return loss(dB)	VSWR	Gain(dB)
1	28	4.232x3.375	0.3449	3.812	4.09	-14.966	4.5578	4.27
2	38	3.591x2.886	0.291	2.21	6.81	-13.77	3.34	6.34
3	40	2.963x2.382	0.241	1.404	8.2	-12.138	1.614	8.2
4	60	2.963x2.438	0.1609	1.93	8.07	-15.659	37.258	3.39
5	80	1.481x1.191	0.1207	2.12	8.72	-11.58	94.85	5.29
6	100	1.205x0.952	0.0966	2.393	8.13	-10.629	2.1424	8.13

Table 3: Dimensions of the patch antenna for the simulation.

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
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

V. SIMULATION AND RESULTS

5.1. Design of antenna structure

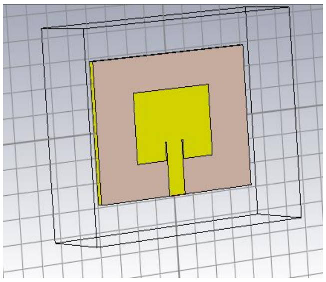

Figure 1:Microstrip antenna

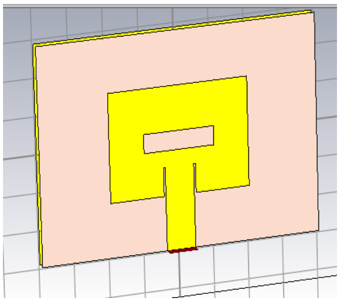

Figure 4: Microstrip antenna with slot

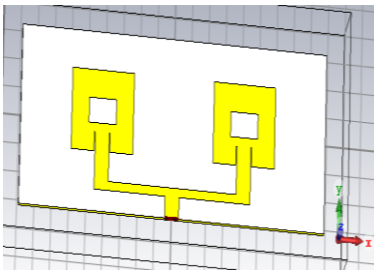

Figure 5:2x1sloted array patch antenna

All the dimensions of the patch are given in Table 3. The construction started with a simple microstrip antenna and the rectangular slot was added on the patch. In order to improve the antenna efficiency, two elements were used in array, one with the same dimensions as the other. The power divider measures 12 mm in length and 1 mm in width. The distance between the feed line's centers is 24 mm. 2x2 antenna patch array was built to further increase directivity and gain. The dimensions are given in Figure 7.

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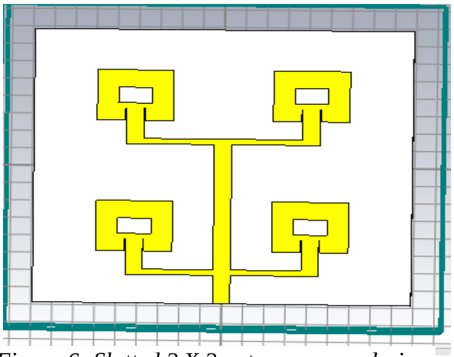

Figure 6: Slotted 2 X 2 antenna array design

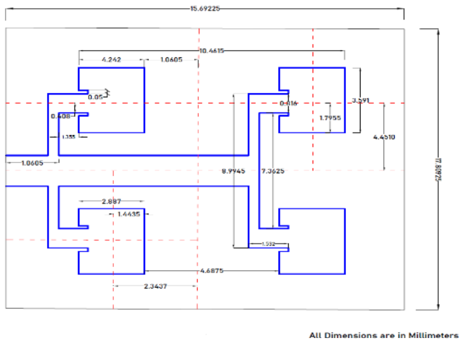

Figure 7: Dimension of 2X2 antenna array

5.2. Performance analysis

5.2.1. Gain

Antenna gain refers to the amount of signal a given antenna will send or receive in a given direction. Gain is determined by comparing the antenna's measured power transmitted or received in a specific direction to the power transmitted or received by a hypothetical ideal antenna in the same situation. The maximum effectiveness with which the antenna can radiate the power transmitted to it by the transmitter towards a target is measured by antenna gain. The gain is calculated for the 1X1, 1X2 and 2X2 array. 2x2 antenna has the highest gain. The results are tabulated in table 4.

5.2.2. Directivity

The degree to which the radiation emitted is concentrated in a single direction is measured by directivity, a parameter of an antenna or optical device. It compares the power density radiated by an ideal isotropic radiator (which emits equally in all directions) radiating the same total power to the power density radiated by an antenna in the direction of its highest emission. The directivity of the 1X1, 1X2 and 2X2. 2x2 antenna has the highest directivity. The results are tabulated in table 4.

5.2.3 . Bandwidth

Another significant antenna parameter is bandwidth. The spectrum of frequencies over which the antenna can correctly radiate or absorb energy is referred to as bandwidth. The optimal bandwidth is often one of the deciding factors when selecting an antenna. Here we design the array of different antenna and compare its bandwidth. The following table show the comparative result.

Table 4: Gain, Directivity and Bandwidth of designed antenna.

Antenna	Gain(dB)	Directivity(dB)	Bandwidth (GHz)	Return loss (dBi)
Patch antenna without slot	5.19	5.19	2.003	-16.01
Patch antenna with slot	6.71	7.14	1.14113	-42.28
1x2 patch antenna array without slot	11.5	11.5	0.733	-9.850
1x2 patch antenna array with slot	11.6	11.9	0.65	-16.57

2x2 patch antenna array with slot	12.7	12.6	0.12	-31.1

5.2.3 Radiation pattern

The Radiation pattern of an antenna represents the energy radiated by the antenna. Radiation Patterns are diagrammatical and graphical representations of radiated energy distribution in space as a function of direction.

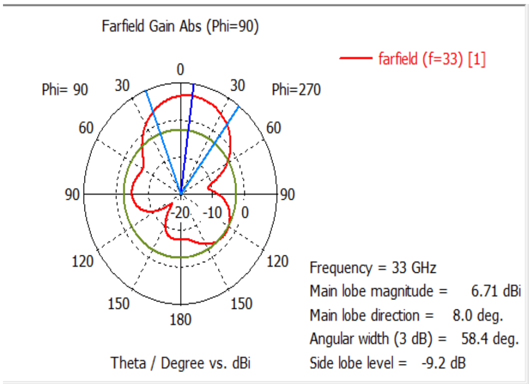

Figure 8: Polar Radiation pattern of simple slotted patch antenna

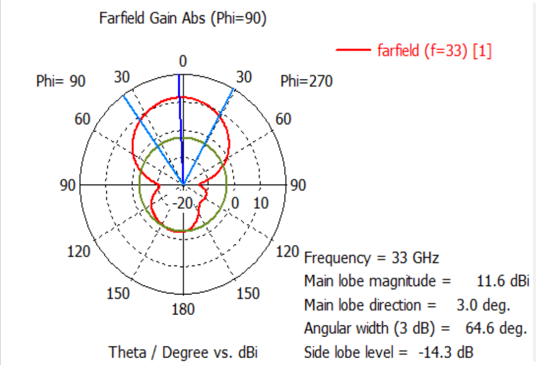

Figure 9: Polar Radiation pattern of 1x2 patch array antenna

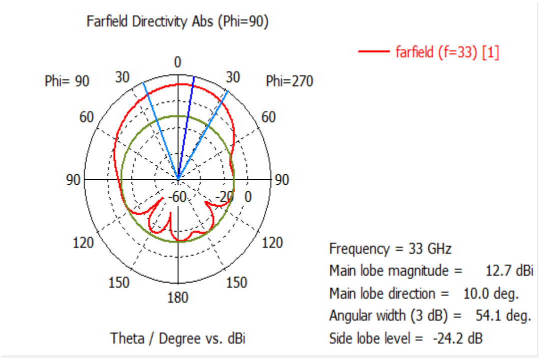

Figure 10: Polar radiation pattern of 2x2 array antenna

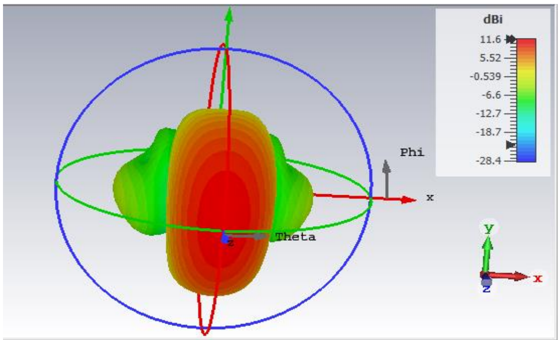

Figure 11:Radiation pattern of of 2x2 array antenna

5.2.4. Return loss

Return loss is the measure of the how well devices or line are matched. A matched is good if the return loss is high. Different system utilizes the different acceptable return loss limit, but in our case, we consider the acceptable limits of 10dBi, which means that if the return loss is below this limit, 90 % of the input power will be transmitted from the antenna.

5.2.5. VSWR

VSWR stand for Voltage Standing Wave Ratio. It is the measure of how efficiently the radio frequency power is transmitted from the power source through the transmission line into the load. In the ideal case, 100% of the energy is transmitted. This requires an exact matching between the source impedance, the characteristics impedance of the transmission line. In the real system, mismatched impedance cause some of the power to be reflected backward to the source and these lets to the destructive interference. VSWR measure of these voltage variances.

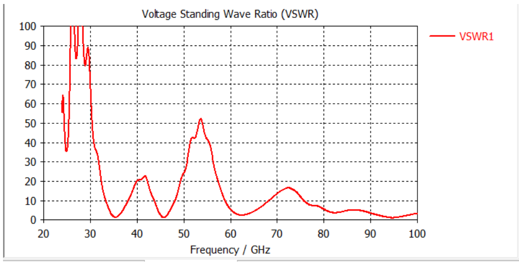

Figure 12: VSWR for 1x2 array antenna

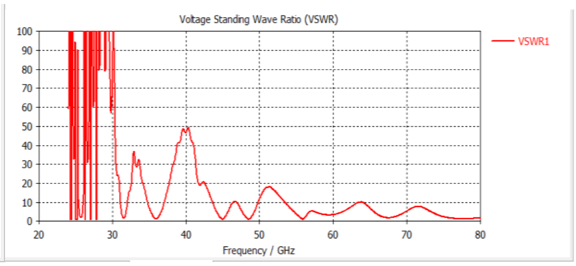

Figure 13: VSWR for 2x2 array antenna

5.2.6. S-parameter

S-parameter describe the input-output relationship between the ports (or terminal) in the electrical system. Literally means, it represents the power transferred from Port M to Port N in a multiport network. S-parameter stand for scattering parameter are used to characterize electrical networks using the matched impedance. Where scattering refers to the way travelling current or voltages are affected when they meet the discontinuity in the transmission line.

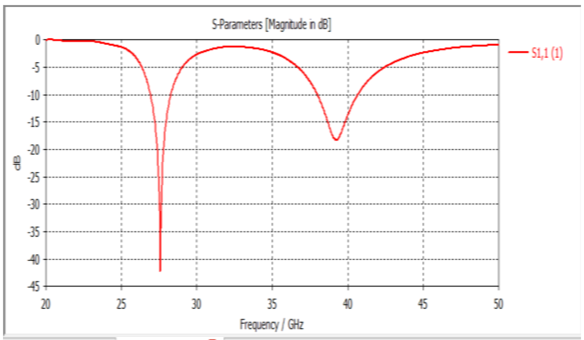

Figure 20: S-paramter for slotted single patch antenna

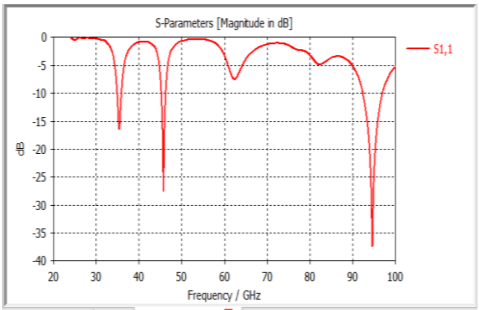

Figure 21: S-parameter for 1x2 array antenna

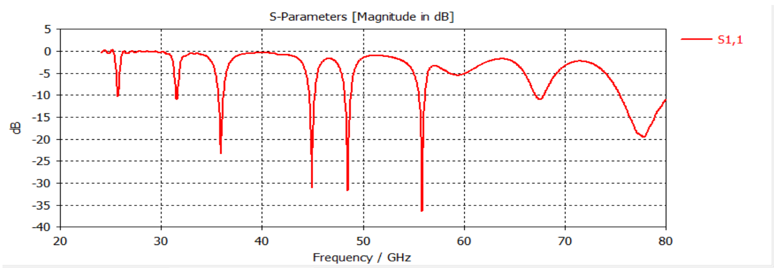

Figure 22:S-parameter for 2x2 array antenna

VI. CONCLUSION

In this paper, the slotted microstrip patch antenna with an array with different number of patch element for the mm Wave dual band patch antenna for 5G communication has been studied. The different arrays of patch antenna design above that are 1x1 antenna with slot and with slot, 1x2 patch antenna array with and without slot and 2x2 patch antenna array with slot operates in the frequency range of 28GHz and 38 GHz in mm Wave communication which falls under the FR-2 frequency band is presented in the paper. Return loss up to -31dBi is achieved with the gain of 12.7 dBi and 12.6 dBi directivity. The compact 5G antenna has been designed, that can be used in mobile stations and base stations. For further improvement of performance of the antenna or to fulfill the requirement of the 5G antenna, the designed antenna can be further extended for massive MIMO purposes to 4x4 or 6x4 array. That will lead to beam steering technique which lets to further improvement in the gain up to 80.4dBi with directivity up to 11.9dBi.

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