Design and Anlysis of 4-Port MIMO Antenna for mmWave Application

Priyadarshini K Desai[a], Dr Basavaraj Neelgar[b]

[a] Asst Prof, Dept of ECE, BNMIT, Bangalore
[b]Prof, Dept of ECE, BNMIT, Bangalore.
Email: [a]priyadarshini.p.r@gmail.com,[b]basneelgar@gmail.com

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Abstract: 5G, the future generation of wireless communication, is mainly focusing on advance various antenna related technologies such as antenna operating mmWave, phased array antenna and massive MIMO, to achieve high data rate of 10Gbps. In this paper a 4-port MIMO antenna is designed, with each element being 2X2 corporate fed, patch antenna array, resonating at 28GHz. The designed antenna is basically suitable for small cell base station antenna operating at mm-Wave frequency. The antenna system can perform beam steering in the horizontal direction, depending on the weights fed to it. The designed antenna array is capable of beam steering in the horizontal direction. Each single element in an 2x2 array, is basically fed using quarter wave transformer, for proper impedance match across the radiating elements and for maximum power transfer to the antenna element. The designed array operates from 27.838 GHz - 28.757 GHz with 900MHz impedance bandwidth. The gain 2x2 array is 14dB and that of the entire array is 20.9dBi when all ports are fed with equal amplitude and in-phase signal with side lobe level of -12dB. The HPBW the array is 11.1 degree. When performed beam steering, the array shows a stable radiation pattern and SLL. The ECC is below 0.05, indicating minimum mutual coupling. It is observed that designed array is stable throughout the impedance bandwidth without much beam-titling. Beam steering in the required direction is done by changing the phase of the excitation signal at available ports.

Keywords: Antenna array, Corporate fed, MIMO, mmWave band, 5G, beam steering.

1. Introduction

The current demand of wireless data transmission and wireless device communication techniques, smart devices have gained lot of popularity, due to this there is huge increase in the data exchange over the wireless communication network [1]. To support the huge data traffic mmWave that offers large bandwidth and can occupy large set users, has drawn greater attention, in the industry and the research community. It is recognized as one of the key technologies to meet the requirement of 5G wireless communication system [2].

A significant amount of research, in the recent years have been carried out in both indoor and outdoor scenarios under mmWave communication. The main motivation to carry out research in mmWave communication are as follows: (a) heterogenous network in near future are expected to offer various services, with the data rate of up to 10Gbps. Though achieving effective communication over large distance, with mmWave seems to be limit, as the signal gets attenuated at a faster rate in comparison with microwave signal, but still it would be able to cover small cell such as pico-cell and femto cells few hundreds of meters offering large bandwidth.(b) Due to tremendous growth of various hardware design and fabrication techniques, such as power amplifier with dynamic range , high gain antenna array, CMOS technology that enable the integration of system components within the small space, that is helpful to for communication in both indoor and outdoor application.

The frequency band at 28GHz and 73GHz, the detailed spatial statistical models of wireless channel were derived. The models provide a practical assessment of small cell operating at mmWave. The details related to these bands is very well discussed in [3].

Although mmWave technology is one of the promising candidates for 5G systems, there exists a gap between the expected commercial mmWave cellular network and existing mmWave prototypes. There are some fundamental changes required in the deployment of mmWave cellular networks. Firstly, need for design of sophisticated antenna, the reason being, long distance communication. When compared with the current technology, there is an increase of path loss by 3dB, with twice the increase in frequency. Thus, deign of sophisticated antenna, with high will make mmWave communication system to overcome long distance communication problem that includes sever signal attenuation. Secondly, at mmWave communication between the access point and base station are very much affected by various obstacle as discussed in[4], that can resolved, with large antenna array, in which radiation/beam can be directed to the required user, with the help of beamforming vector or weights , which are calculated using OMP algorithm for mmWave, that helps in saving power, by orienting the beam in the required direction.

Above reason being the motivation for the work discussed in this paper. Paper discusses antenna array design that are used for indoor and outdoor application. With the design of high gain, high directive antennas beam steering techniques one can overcome severe path loss and can meet the user mobility, i.e. in getting access link for both indoor and outdoor scenarios.

One of the contributions of this paper is a corporate feed, antenna array that is validated to be suitable for indoor mmWave communication by considering factors such as the antenna array gain, directivity, beams steering. In this paper, 4-port rectangular patch antenna array operating at 28GHz is proposed. Individual port is connected to 2x2 corporate fed antenna array. Each antenna element in the MIMO is corporate fed, with quarter wave transformer for perfect impedance matching and maximum power transfer.

2 Design and analysis of 4 element antenna array with the corporate feed

Working and Design equation of Patch: Micro strip Patch antenna consists basically dielectric substrate that is, sandwich between two metallic surfaces, one operates as a ground surface and the other is the radiating patch. When the excitation signal is applied to a patch through proper feed line the waves generated within the dielectric undergo reflections and energy is radiated from the edges of the metal patch. There are different feed techniques to excite the radiating patch. The micro-strip feed line is the simplest among all the feeding technique. The rectangular patch is excited through a 50Ω ohm micro-strip line.
The design equation for the radiating patch is shown below:

$$Wp = \frac{c}{2f_0\sqrt{\frac{\epsilon_r+1}{2}}} \tag{1}$$

$$L = L_{eff} - 2\Delta L \tag{2}$$

$$\Delta L = 0.412h \frac{(\epsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\epsilon_{eff}-0.258)(\frac{W}{h}+0.8)} \tag{3}$$

$$L_{eff} = \frac{c}{2f_0\sqrt{\epsilon_{eff}}} \tag{4}$$

$$\epsilon_{eff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}[1 + 12\frac{h}{W}]^{-1/2} \tag{5}$$

The rectangular radiating patch is designed on FR-4 Substrate with dielectric constant of 4.3 and the thickness of 0.127mm. As the operating frequency is in terms of GHz thickness of substrate is taken to be small. The simulation is carried out n CST microwave studio. The lossy copper material is used as the patch element and feed line.

Corporate feed Network: One of the advantages of microstrip antennas is the feeding technique. The feeding techniques should be simple and easy to fabricate. In different combination of feeding techniques are available when antenna array is considered such multiple line or single line, depending on the system requirements.

Among the different feed techniques, most of the popular fed technique that is used for microstrip antenna array is the corporate feed. In Corporate feed uses the power splitter of 2n (n=2,4,8). In corporate fed power splitting is done by using either quarter wavelength transformers or by tapered lines. In this paper corporate fed is used to excite 2x2 antenna elements wherein using the quarter wavelength transformer is used for impedance matching.

Corporate-feed arrays are more versatile. As the feed network have the length fixed, phase variation across the transmission line is minimum, which is much required or say ideal for scanning phased array. Thus, a corporate feed provides better radiation efficiency, directivity and reduced beam fluctuations over a band of frequencies when compared to the series feed array discussed in [5]. Individual element amplitude can be adjusted using either attenuator or amplifiers, wherein phase can be controlled by using phase shifter. Input power, in case of corporate feed network is equally split at each junction of the microstrip array. Table1 below gives the obtained dimension of rectangular patch and feed network details

Table1: Dimension of rectangular patch and feed network

Element	Width(mm)	Length(mm)
Rectangular Patch	4.8	3.3

Feed line of 50 ohm	0.113	2.253
Feed line of 70 ohm	0.095	2.025
Feed line of 100 ohm	0.0067	4.274
Rectangular Patch	4.8	3.3

The designed 2x2 rectangular patch array with corporate feed is shown figure 1(a) and figure 1(b) indicates that all radiating elements are exactly in-phase, and the array has standing wave behavior over the entire array, figure 1(c) shows the reflection coefficient S11 is well below -10dB at 28.303 GHz. The obtained results also indicate that the array offers impedance bandwidth of 900MHz from 27.838 GHz to 28.757 GHz.

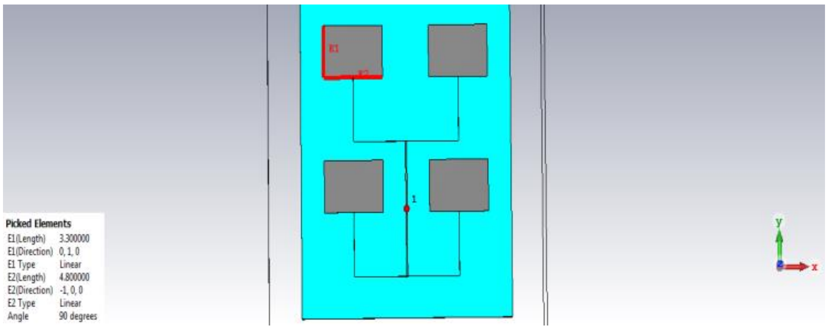

Fig 1(a): 2x2 Rectangular Patch Antenna array with corporate feed.

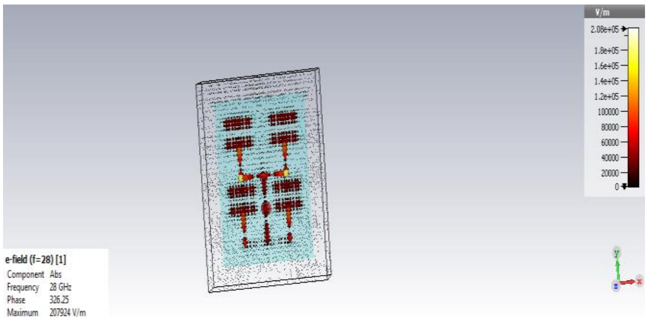

Fig 1(b): Surface current Density

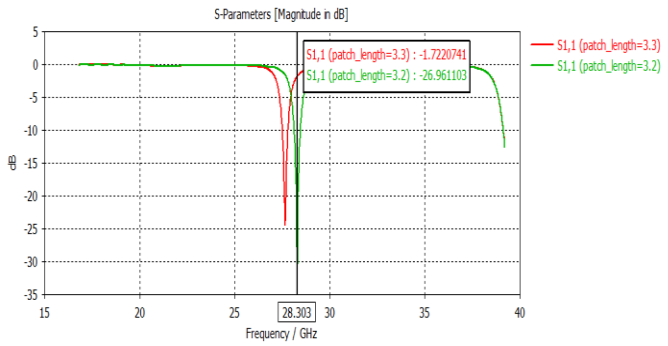

Fig 1(c): S_{11} Parameter at 28GHz

3.Performance of 4-Port MIMO Array

The designed 4-port MIMO with individual element being 2x2 rectangular array corporate feed array is shown in figure 2 (a). The inter element spacing is taken to be the greater than half wavelength. İn figure 2(b), it can be observed that mutual coupling between elements is less that -20dB in the operating bandwidth.

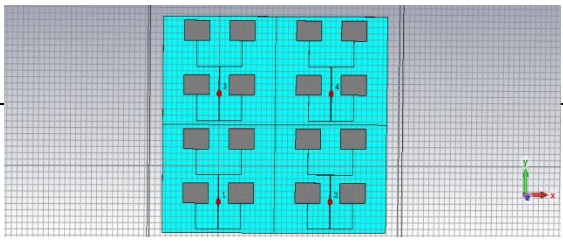

Fig 2(a): 4-Port MIMO Patch antenna Array

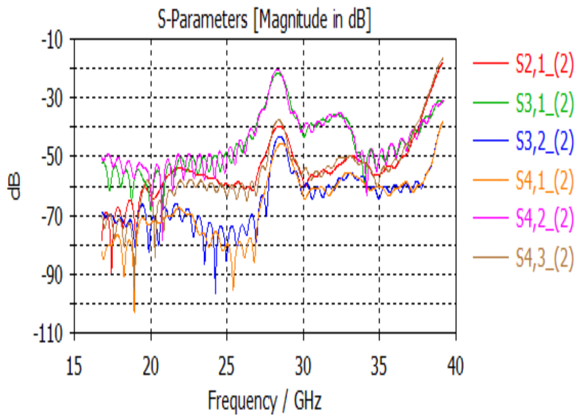

Fig 2(b): Mutual Coupling between the Array Elements

The radiation pattern, with all port fed with excitation signal of equal phase and equal amplitude, the obtained directivity is around 20.1 dBi shown in figure 2(c) , it is noted that for the bandwidth of 900MHz the radiation is stable, with no tilt in the main lobe.

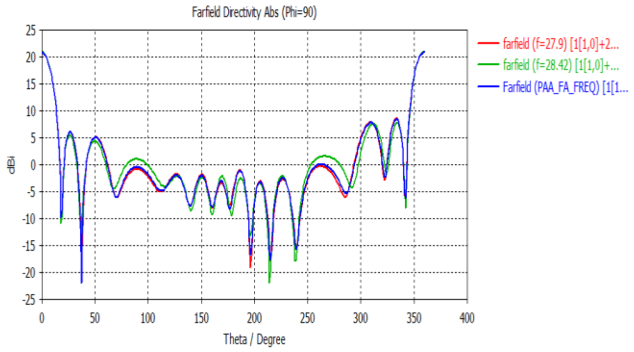

Fig 2(c): Radiation Pattern and the directivity of 4-Port MIMO Antenna Array

Figure 2(d) show beam steering, that can be performed with each port fed by the weights generated from the buttler matric and/or connecting the ports with different amplifier and attenuators. Time delay is the quantifiable delta in phased array, needed for beam steering. Usually the time delay is realized in terms of phase shift, that is more practical in the implementation of phase variation in phase array.

For the designed array, the boresight direction is perpendicular to the antenna array. To visualize the phase shift needed to steer the beam , a very small change /phase shift between the adjacent element is given. İt can observed that that radiation pattern reamins unchaged through out the steering angle

As the considered planar sub-array i.e. (2x2 antenna array) placed at distance greater than half wavelength , with unequal inter-element spacing , the signal arrives/to be transmitted at any arbitrary degree from the mechanical boresight that theta=0, the optimal phase shift between the elements can give, so that the signals get added in phase.

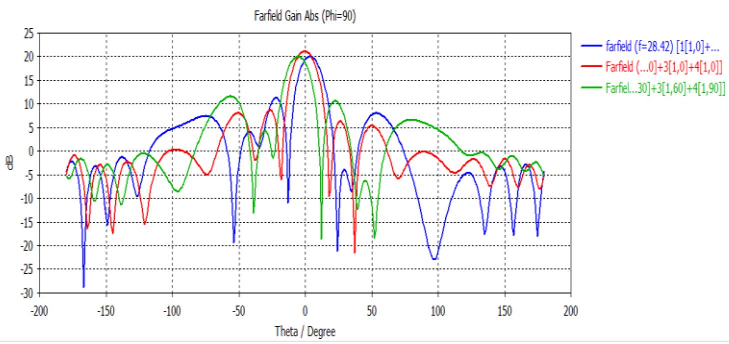

Fig 2(d): Beam steering of Antenna Array

The figure 2(e) shows the plot of ECC for the designed MIMO system. The ECC should be less than 0.05. it can be noticed that the ECC over the operating frequency range is less than 0.05 and is computed using s-parameters.

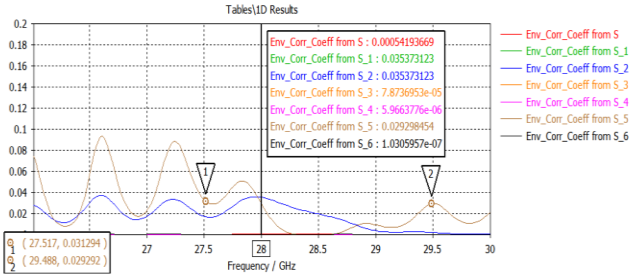

Fig 2(e): ECC of MIMO Antenna (from 27.5GHz-29.5GHz)

4.Conclusion

The designed 4-Port MIMO antenna system offers stable radiation pattern over the bandwidth of 900MHz, which is high bandwidth. Antenna array offers directivity of 21dBi, with mutual coupling amongst the ports lies less than -17 dB, which implies there is hardly any effect of the coupling between the elements. The beam steering can be carried out in the required direction by exciting the adjacent/neighboring ports with the required phase. The designed antenna array stands promising to meet the required gain for small cell base station antenna in 5G.

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