A wideband probe-fed low cost mm wave fractal antenna array for 5G

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Abstract. Antennas for 5G needs to be compact, low-cost and of broad band. The proposed antenna is a co-axial fed Sierpinski fractal antenna of 1st iteration which satisfies most of the important requirements for prospective 5G cellular communication. The proposed design has broad impedance bandwidth of 2.6 GHz at resonant frequency of 28.2 GHz and suitable radiation pattern for beam steering. Various characterization studies are performed to achieve beam steering. An L-shaped array of the proposed antenna is designed for this purpose. This array is also placed on a generic smartphone mock-up and the radiation pattern is characterized.

1. INTRODUCTION
The new approach of 5G is based on improved utilization of current frequency bands (up to 6GHz) and exploitation of new frequencies in the centimeter/millimeter wave bands (somewhere between 6GHz and 100GHz), to deliver the necessary capacity and coverage. The opted frequency by many researchers for 5G is 28 GHz so as to increase data rate [1]. There is a need for low-cost antennas of smaller size and higher bandwidth [2][8].

There are different types of antennas proposed for prospective 5G such as edge-fed slotted patch antenna, U-shaped patch antenna, dielectric resonator antennas etc. [2][3][4][9]. Slotted patch antenna suffers high propagation. Though the antenna has broadband design, beam steering is not illustrated and the antenna structure is relatively complex to fabricate due to multiple stacked layers [5][6][7].

The proposed antenna is a co-axial fed mm-wave fractal antenna with bandwidth of about 2.6 GHz. It is low-cost due to FR4 dielectric and compact of the size 0.68λ at 28.2 GHz. Optimization studies to tune the impedance bandwidth is carried out. An L-shaped array of the proposed antenna is chosen among the different geometries in order to have optimized beam steering.

Case study of antenna array placement on a generic smartphone is also presented. The result of these studies leads to a design of the L-shaped antenna array that has better beam steering than other designs of the array.

2. ANTENNA DESIGN
Coaxial-Fed Fractal Antenna: Coaxial feed antenna reduces the RF real estate in a smartphone. It is more convenient to be designed on the motherboard of a smartphone when compared to an edge feed patch and also it enhances beam steering ability of the antenna. Figure 1 shown below is the
preliminary design of the coaxial feed for the antenna which is made of the low-cost FR4 as the dielectric material. The feed has a diameter of 0.24mm and height of 1.6mm. The dielectric material of dimensions 6.8x7.2x1.6 mm.

The antenna has a dimension of 9.478x9.478 mm. The feed is located at 4.86mm from its corner. This is designed in order to achieve the required resonance and to tune the impedance bandwidth.

2.1. UNIT CELL
Fractal Antenna- Sierpinski Triangle

2.1.1. Zeroth iteration As shown in the figure 2, the antenna is an equilateral triangle with all of its sides, a=5.59mm.

2.1.2. First iteration As shown in the figure 3, a triangular piece in the middle of the 0th iteration antenna is cut out. The cut out triangle has all its sides, b=2.683mm. This is the most optimum antenna structure as it matches most of the requirements such as the opted operating frequency for 5G of 28.2 GHz and considerable bandwidth of 2.6GHz.

2.1.3. Second iteration As shown in the figure 4, the antenna has two more equilateral triangles cut out from the 1st iteration antenna. The smaller triangles have all their sides, c=1.36mm. This study was performed to investigate any possible improvements in the bandwidth from that of the previous iterations. It revealed that this study showed no improvements with respect to 1st iteration and thus limited us to opt the 1st iteration of this antenna.
2.2. ARRAY ARCHITECTURE DESIGN

Due to high attenuation of atmosphere at mm Wave frequencies, it is important to design high-gain, beam steering antenna systems for which three array designs of the proposed antenna are discussed in the following.

2.2.1. Array across the length. As shown in the figure 5, there are about eight antennas joined to form an array. The distance between the feeds of two consecutive antenna is 7.2 mm or 0.68Z at 28.2 GHz.

2.2.2. Array across the width. An array of nineteen antennas are joined horizontally to form an array as shown in figure 6. The distance between the feeds of two consecutive antenna is 6.8 mm or 0.639 Z at 28.2 GHz.

2.2.3. L-shaped array. As shown in the figure 7, nineteen horizontal antennas along with seven vertical antennas are combined to form an L-shaped array. These widths were chosen because the L-shaped array would perfectly fit on our designed smartphone mock-up. The distance between two horizontal consecutive feeds is 6.8mm and between two vertical feeds is 7.2mm at 28.2 GHz.
3. GENERIC SMARTPHONE MOCK-UP DESIGN

As shown in the above figure 8, the body has the dimension of the motherboard of a typical 5-inch smartphone made of FR4 material and has a thickness of 0.5mm. It consists of a camera module, a 3.5mm Audio port, two micro-SIM slots, a micro SD memory card slot, a charging port, microprocessors and resistors. The design data was obtained by dismantling an old smartphone and typical components were mimicked.

All the components are made of respective materials and resemble the components of a typical smartphone. The microprocessors shown here are made of ceramic plate with metal beads soldered in between the plate and PCB. The resistors have the body made of ceramic, and are soldered with metal pins on either sides. The two micro SIM card slots are of the dimension 12.2x15.2x1.2 mm. The micro SD memory card slot is of the dimension 11.2x15.2x1.2 mm. Antenna array placement analysis on this mock-up is proposed.

4. FABRICATED ANTENNA

The partially fabricated antenna is shown below in figure 9. The array is also planned for fabrication.
5. RESULTS AND DISCUSSIONS

5.1. UNIT CELL
As shown in the figure 10, the resonant frequency is 26.9 GHz but the return loss is less than -5 dB throughout the graph. Thus this design is not accepted.

![Figure 10. Return loss of zeroth iteration antenna at 26.9 GHz](image)

As shown in the figure 11, the resonant frequency of the proposed antenna is 28.2 GHz and the bandwidth is around 2.6 GHz and also it is easy to fabricate the antenna and form an array of it. Thus, leading to the best design.

![Figure 11. Return loss of proposed Antenna at 28.2GHz](image)

As shown in the figure 12, the resonant frequency of this antenna is 28.2 GHz and the bandwidth is around 2.8 GHz but due to difficulty in fabrication of unit cell and array we do not prefer this design.

![Figure 12. Return loss of second Iteration of Fractal Antenna at 28.2GHz](image)
Figure 13 and Figure 14 represent E-Plane and H-Plane of the Proposed antenna respectively and this pattern is suitable to be considered as an array candidate due to the isotropic nature of the proposed antenna.

Figure 13. E-plane Radiation Pattern of proposed antenna at 28.2 GHz

Figure 14. H-plane Radiation pattern of proposed antenna at 28.2 GHz

5.2. ANTENNA ARRAY

Figure 15. Beam steering of antenna array across the length at 28.2 GHz
Figure 15 shows the beam steering or beam tilting of antenna array of 8 elements in free space and from this we can see that the beam width is 9.24 degrees in azimuth plane.

![Figure 16. Beam steering of antenna array across the width at 28.2 GHz](image1)

Figure 16 shows the beam steering or beam tilting of antenna array of 19 elements in free space and from this we can see that the beam width is 5.138 degrees in elevation plane. We observe that bandwidth has decreased from the previous design due to the increase in array elements.

![Figure 17. Beam Steering of L-shaped antenna array at 28.2 GHz](image2)

Figure 17 shows the beam steering or beam tilting of antenna array of 26 elements that is in L-Shape in free space and from this we can see that the beam width is 3.692 degrees in elevation plane. We observe that bandwidth has even further decreased from the previous design due to the increase in array elements. The 3D polar plot of L-shaped array is shown in the figure 18.

![Figure 18. 3D Polar plot of L-shaped array at 28.2 GHz](image3)
5.3. ANTENNA PLACED IN SMARTPHONE MOCK-UP

The L-shaped antenna as shown in figure 7 is placed on the smartphone mock-up and the results are analysed. L-shaped antenna is designed so as to ensure steady connectivity by beam steering. The reason behind the mentioned dimension of the array is that it can be properly placed on the mock-up without any obstruction or overlapping with other components. As the mock-up was electrically large when compared to the proposed antenna, the placement analysis of the antenna array on the mock-up was made with the help of Ansys HFSS IE. As shown in the figures 19 and 20 below, there is a very slight deviation in the radiation pattern of the mounted array to that of the array kept in free space in both Azimuth and Elevation planes.

Since the speckle is less than 10dB below the main beam, it is found to be advantageous.
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