Designing Multiband Millimeter Wave Antenna for 5G and Beyond

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Abstract. In this work, we have presented microstrip low profile patch antenna at Millmeter wave (mmWave) for 5G and future communication. There are two designs presented in this work. The first, we designed a dual band in 5G new radio (NR) specified frequency bands of 27 GHz and 37 GHz. We achieved the design with maximum gain of 8 dB. In the second design, we modified the structure to obtain multiband; again, in the International Telecommunication Union (ITU) specified possible bands for mobile communication. The design was optimized for 5 different bands that is, 28 GHz, 35.5 GHz, 41 GHz, 51 GHz and 60 GHz. We obtained reasonably good bandwidth in each band. The basic patch dimension is 12.5×10.1 mm^2. In order to increase the gain of the basic element, the array of antenna is designed. Linear array with element up to 10 is designed and simulated. It is observed that an increase in the gain of around 3 dB gain is achieved. On optimization, it is found that with 6 element array the performance is relatively better on both basic bands.

Keywords: MmWave antenna · Multiband mmWave antenna · 5G mobile communication · Array antenna · 27 GHz and 37 GHz

1 Introduction

5G networks are being globally deployed at rapid pace. This 5G wireless communications and network is design to provide fiber like experience to users [1, 2]. Many new techniques like massive multiple input multiple output (MIMO), advanced coding, and mobile millimeter wave (mmWave) have been developed and being investigated. At the same time, network capacity is expected to be increased approximately 100x. To expand the network capacity, 5G new radio (NR) air interface enables diverse spectrum in both, the sub-6 GHz and mmWave frequency bands [3]. This additional spectrum required by 5G brings new challenges for product design and global deployment, especially in the mmWave frequency range [4]. To achieve high data rates assured by 5G, the antenna system becomes a crucial component in the overall system design.

Additionally, higher frequency bands in mmWave have been proposed in 5G and backhaul network [5]. Therefore, the requirements of multiband antenna especially in these higher bands and with significant bandwidth are increasing. Furthermore, a dual

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band multi-band operation with polarization diversity finds useful applications in current and the next generation of wireless systems [6]. Not only that, a dual-band antenna with different I/O ports is also preferable in many practical applications. However, most of the integrated designs work at a single band and polarization [7]. And, due to the asymmetrical structure of the radiation elements, most of the designs are not appropriate for dual-polarization applications. Also, the gain from one single antenna is found to be limited from 3–6 dB. High gain and directivity requirements can be obtained by array of antenna elements where individual radiating beams of each antenna are pooled to provide a high directivity. Authors in [8], designed and discussed a dual frequency quarterwave shorted microstrip patch antenna for satellite MIMO application to achieve relative higher gain.

Several efforts are made in antenna geometries as well as array configurations at microwave and mmWave frequencies including at 28- and 38 GHz [9, 10] to provide improved gain and bandwidth. In many reported antennas design, the desired performance is linked with design complexities usually because of multilayer structures. Such design leads to high fabrication cost. Moreover, mmWave antenna design is mostly focused on planar configurations. However for 360° area coverage, integrated array on four faces of a cube with two antennas on each face [11] are used. Yet in another approach [12], multi-faceted phased array is investigated. In this, conformal microstrip antenna arrays are presented for continuous conformal surfaces at 35- and 32 GHz. In [13], different multiband antenna configurations for 28/38 GHz have been demonstrated for 5G applications. A dual band 27/37 GHz with approximately 3 GHz bandwidth and over 8 dB gain is also presented in [14]. However, most of the works are dual band or 3-band with limited gain and bandwidth. In [15], authors tried to design a slot antenna for wider bandwidth. Additionally, in lower band of frequencies such as sub-6 GHz, there are multiple designs available with multiband [16–18].

In this work, we present a design of 5-band mmWave antenna. The bands are: 27 GHz, 35.5 GHz, 41 GHz, 51 GHz and 60 GHz. The bandwidth in each case is more than 1.3 GHz and the gain varies from over 6 dB to 8 dB. This is interesting results. In order to increase the gain, we also designed linear array of antennas but with basic dual band antenna. For the array, the feed is given only for the first element, remaining patches act as the passive elements. The passive elements get the fringing effect + the radiation of previous element as feed and then they radiate. Number of elements was tried in the array to ensure optimum gain on both the frequency 27/37 GHz band. It is observed that the array with 6-elements offer approximately 1.5 dB gain in the lower band while close to 3 dB gain in higher band.

Rest of the contents in the paper is arranged as follows. Section 2 presents the design of antenna while results are presented in Sect. 3. In Sect. 4, the conclusion is given.

2 Design of Antenna

2.1 Theoretical Calculation of the Basic Patch

Initially, a micro strip patch antenna was designed at 27 GHz of frequency for which width and length is calculated. The width of the patch is given as:

$$w = \frac{c}{2fr}\left(\sqrt{\frac{2}{\varepsilon_r + 1}}\right) \tag{1}$$

where ***fr*** is the centre frequency and ε_r is the permittivity. However, normally effective permittivity is used to avoid fringing effect present during the design. It is given as:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + \frac{2h}{w}}}\right) \tag{2}$$

where, h is the height of the substrate. The length is calculated as the effective length by including the resonant frequency and the effective relative permittivity. The total length is calculated as the $L_{eff} - 2\Delta L$.

$$L_{eff} = \frac{c}{2fr\sqrt{\varepsilon_{eff}}} \tag{3}$$

$$\Delta L = h \times 0.412 \times \frac{\left(\varepsilon_{eff} + 0.3\right)\left(\frac{w}{h} + 0.264\right)}{\left(\varepsilon_{eff} - 0.258\right)\left(\frac{w}{h} + 0.8\right)} \tag{4}$$

$$L = L_{eff} - 2\Delta L \tag{5}$$

The basic structure of the antenna is developed by using the above calculation.

2.2 Dual Band Design

Initially, a dual band millimeter wave antenna is designed to operate in the millimeter wave centered at frequency 27.5 GHz and 35.7 GHz [10]. The thickness of the designed antenna is 0.87mm and the substrate material used is Rogers Duroid 5880 (RT Duroid 5880). The relative permittivity is 2.2. The strip line feeding technique is used to feed the antenna structure. The design is shown in Fig. 1 and the corresponding dimensions are shown in Table 1.

2.3 Multiband Design

Several changes in structure were tried to get bands without degrading the obtained parameters from the basic element (Fig. 1). In the process, we duplicated the basic antenna and connected through a rectangular patch of length 13.05 mm that is, 13.05 mm apart as shown in Fig. 2. The patch width is 0.6mm and position of the patch from the feed is 2.2 mm. This structure offered 3^{rd} band at 41 GHz. We continued the design with many other structural changes but then found more bands when another rectangular patch at the center is connected. However, with only centered connected patch (as shown in Fig. 3), we obtained 4-bands with additional band at 60 GHz. Such approach encouraged us to find more operating bands. Our objectives were to get multiple bands in the operating frequency up to 62 GHz. We then kept two of the rectangular patches (centre and edge) as shown in Fig. 4. With optimized distances and dimensions, we obtained 5-bands of interest. Important dimensions are labeled in the Table 1 itself.

Table 1. Dimensions of the single element Antenna

Dimension	Value
L1	6.7
L2	8.1
L3	2.2
L4	6.7
L5	2.2
L6	0.2
L7	0.7
L8	1.9
W1	0.6
W2	2.9
W3	0.9
W4	1.4
W5	1.5
a	0.2

2.4 Antenna Array Design

To obtain higher gain, we created array of antenna. For this, we started with basic elements and its array. That is, dual band (Fig. 1 design) with higher gain. The spacing between the antenna elements is λ/2 i.e., 5.45 mm from the edge of the *T*-structure and the same distance is maintained for all the elements. The antenna array has a series fed structure. The first antenna element is feed by using a coaxial feed technique. The elements next to the first element will receive the radiation from the first, of course, may be with some propagation delay. Multiple elements are linearly connected to offer more gain. We obtained maximum gain at both frequency bands. On optimization, it is found that with 6 and 10 elements array, the gain is approximately the same.

Slightly decrease in the gain of lower band with 10-element array is observed. Therefore, we concluded that 6-element array performs optimal in this type of feeding. The array with 10-element is shown in Fig. 5.

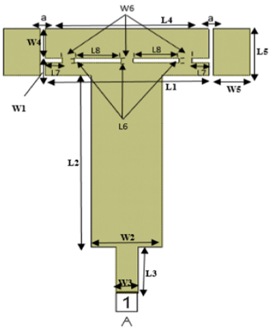


Fig. 1. Dual band antenna

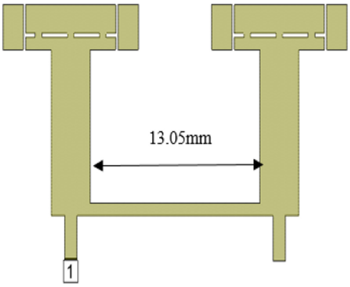


Fig. 2. Antenna array with edge connection that gave the 3rd band

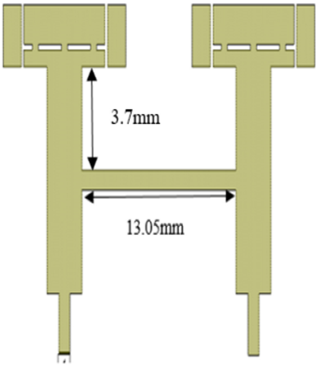


Fig. 3. Antenna element design that produced the 4th band

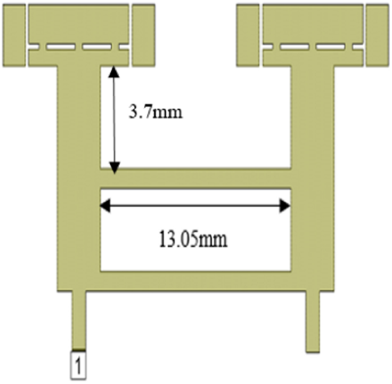


Fig. 4. Multiband (5) antenna elements that produced 5 bands

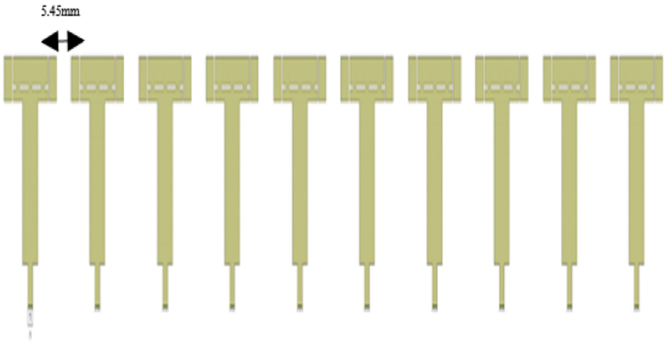


Fig. 5. Antenna array with the basic elements

3 Results and Discussion

As mentioned before, we used design in applied wave research software (AWR). Figure 6 illustrates S11 parameter of 3-bands from the design of Fig. 2 (Antenna array with edge connection that gave the 3rd band). Though, it was not an objective, however, it is also found to be of practical use. We see the 3-bands at 27 GHz, 37 GHz and 41 GHz. The S11-parameters for the three bands are −14.35 dB, −23.52 dB and −49.61 dB which are reasonable. The gain plot for different frequencies is shown in Fig. 7. Figure 7(a) shows the gain at 27.8 GHz which is 8.66 bdB. The gain at 35.8 GHz is 9.707 dB and that of at 41.1 GHz is 6.185 dB are shown in Fig. 7(b) and Fig. 7(c) respectively. They are also comparable, in fact, better than most of the designs considering single element multiband.

The S11-parameter of the antenna design of Fig. 3 (Antenna element design that produced the 4th band) is shown in Fig. 8. It is to be noted that this design has resulted into 4-bands with the last being at 60 GHz.

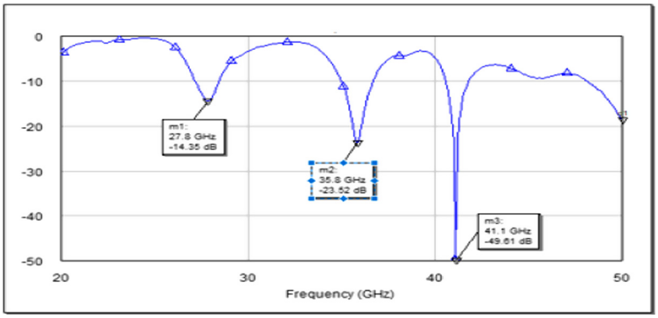
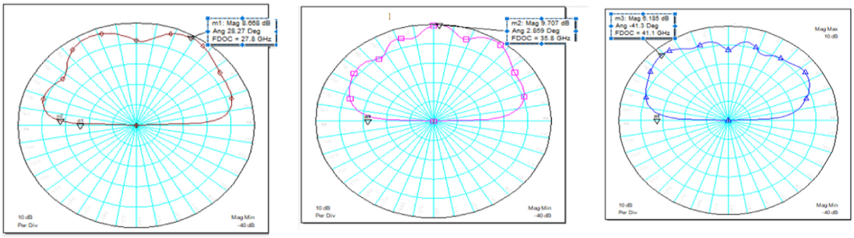


Fig. 6. S11 parameters for edge design



(a) **(b)** **(c)**

Fig. 7. (a) Gain at 27.8 GHz (b) Gain at 35.8 GHz (c) Gain at 41.1 GHz

The frequency bands are 28 GHz, 36 GHz, 41 GHz, 59 GHz and their respective reflection coefficients are −11.4 dB, −16.6 dB, −2029 dB and −22.11 dB. The gain is also in the range over 6 dB to 9 dB as shown in Fig. 9(a)–(c).

The final multiband design (Fig. 4) has resulted in a 5-band where the center frequencies and the reflection coefficients are at 28 GHz, S11 is −18.53 dB; at 36 GHz,

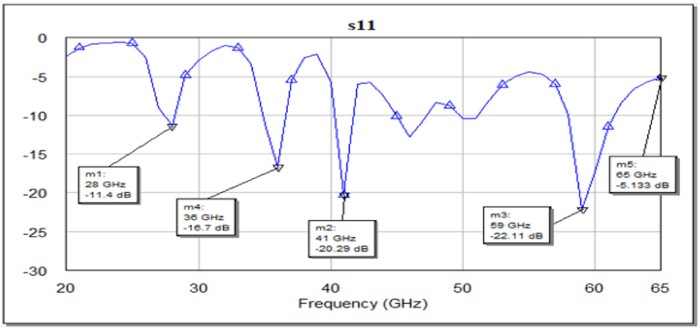
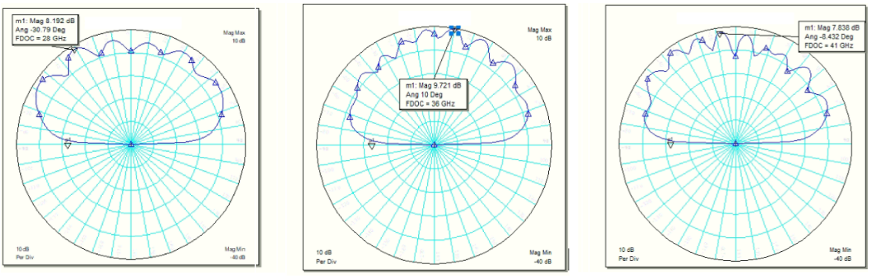


Fig. 8. S11 of 4-bands from design



(a) **(b)** **(c)**

Fig. 9. (a) Gain at 28 GHz (b) Gain at 36 GHz (c) Gain at 41 GHz

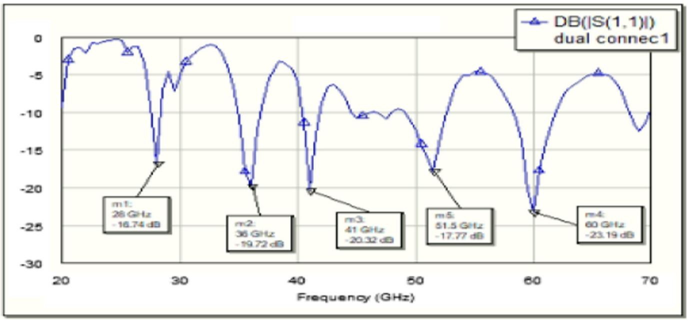
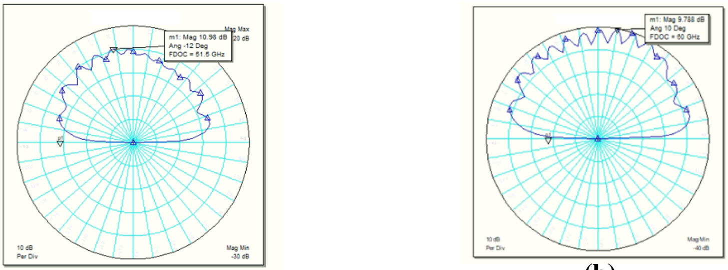


Fig. 10. S11 parameters for the final multiband design

S11 is −19.72 dB; at 41 GHz, the reflection coefficient is −20.38 dB; at 51.5 GHz, S11 is −21.94 dB and, finally at 60 GHz, S11 is −21.1 dB which is shown in Fig. 10. Similarly, the gains remain intact in the range 6.89 dB to 9.6 dB in all the bands. The corresponding gains at 51.5 GHz is 10.98 dB and at 60 GHz the gain is 9.788 dB which is shown in Fig. 11(a) and (b).

We also simulated the performance of array design as shown in Fig. 5. With 6-element array, the performance on both bands is found to optimum. The center frequencies of the



(a) **(b)**

Fig. 11. (a) Gain at 51.5 GHz (b) Gain at 60 GHz

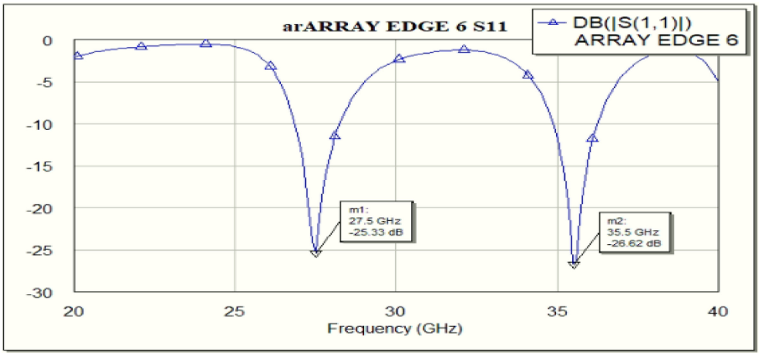


Fig. 12. S11 parameters for Array design

array with passive elements are 27.5 GHz and 35.5 GHz and, the reflection coefficients as −25.33 dB and −26.62 dB is shown in Fig. 12. The corresponding gain at 27.5 GHz is 7.739 dB and at 35.5 GHz it is 9.924 dB. The same result is summarized in Table 2.

Table 2. Summary of the final design of the multi band antenna design

Number of antenna elements	Center frequency (GHz)	S11 (dB)	Gain (dB)
6	27.5	−25.33	7.816
	35.5	−26.62	10.6

Finally, overall results are listed in Table 3 for final design of 5-band mmWave antenna. We observed that a single antenna can be designed to operate in wide band in mmWave from 28–60 GHz with good bandwidth and gain over 8 dB.

Table 3. Summary of the final design of the multi band antenna design

Center frequency (GHz)	S11(dB)	Gain	Bandwidth
28	−16.74	8.192	1.23
36	−19.72	9.721	1.91
41	−20.32	7.838	1.51
51.5	−17.77	10.58	3.81
60	−23.19	9.788	3.62

4 Conclusion

Work in this paper describes multiband (5-band) operating from 27 GHz to 60 GHz operating frequencies in mmWave. Most of the frequencies are in 5G specified band and backhaul. It is also expected to be in future usage as these bands are identified by ITU for mobile communication. Achieved gains are reasonably good (above 7.8 dB to around 10 dB). We also presented our first attempt towards increasing the gain with array of antennas. Some important observations like maximum number of elements with passive feed is realized and obtained. In creating multiband, we have also optimized the gain and bandwidth. Bandwidth in each case is above 1.3 GHz. Interesting results and observation with structural changes are found. It is seen that more bands might result if basic frequency is started from around 40 GHz instead of what we have taken as 27 GHz. Our work is in progress for optimization, fabrication and characterization.

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