A non-uniform excitation Antenna array with defected ground structures for Dual-band 5G mm-wave Applications

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Abstract. In this paper, the authors present a non-uniform excitation antenna array with defected ground structures for 28GHz and 40GHz mm-wave applications. The proposed antenna array is simulated using HFSS Ver. 18.2 to analyze the radiation and reflection characteristics. Authors used RT Duroid ($\varepsilon_r=2.2$) with a thickness of 0.782 mm to design the antenna array. To improve the gain and bandwidth, Defected Ground structures are used in the proposed design. Use of Dolph Chebyshev distribution of excitation amplitudes miniaturized the antenna array. The proposed design exhibited a fractional BW of 23.33% and 5.56% at 28GHz and 40 GHz respectively. A peak gain of 8.8 dB and 7.7 dB at 28 GHz and 40 GHz respectively is observed in the simulation results.

1. Introduction
The rapid advances in wireless communication technology are enabling the replacement of LTE and its derivatives with the emerging robust 5G technology. 5G is popularly known for its characteristics like low latency, higher bandwidth, higher capacity and support to mobility. The emerging 5G technology attracted many researchers as the mm waves play a significant role in many industrial and scientific applications. Few among them include radio astronomy, remote sensing, radar systems. The large bandwidth is one of the critical requirements for 5G technology to decrease latency and support higher data rates. The explosive growth in connected devices such as laptop, smartphones, wearable devices and home appliances etc. created excessive demand for large bandwidth to support higher data rates. 4G technology is unable to address some of the major problems of present wireless communication systems, that include poor coverage, poor quality over crowded channels and bad interconnectivity [1]. The physical dimensions of the mm-wave antenna are tiny. The major challenge for the present researchers in mm-wave antenna design is to maintain precision in fabrication and to get an efficient antenna. Therefore, it is vital to adopt new techniques for designing antennas for 5G mm-wave communication. A variety of approaches are reported in the literature for improving gain and bandwidth. To achieve the notched frequency band of 30-35 GHz, Haraz et al. [2] created an L shaped slot in the feed line.

Arizaca et al. [3] reported a parallel fed array with uniform excitation to demonstrate the improved gain. In [4], Rahayu et al., presented a non-concentric triangles DGS antenna to show bandwidth improvement. Khattak et al. [5] achieved dual-band behaviour using the elliptical slot in a circular patch antenna array. In [6], Nanae et al. designed a $2 \times 2$ rectangular patch antenna array with U slot to achieve wideband behaviour. To obtain the wideband array response, Sharawi et al. [7] utilized the concept of Connected Antenna Arrays (CAA).
In this paper, the authors developed a 1 x 4 non-uniform (Dolph-Chebyshev) amplitude excitation array resonating at 28 GHz and 40 GHz. The designed antenna array is miniaturized and exhibits good resonance and radiation characteristics at desired mm-wave frequencies.

2. Design of Antenna Array

A non-uniform excitation corporate fed antenna array is designed with excitation coefficients $a_1=1$, $a_2=1.6678$, $a_3=1.6678$ and $a_4=1$. Since the non-uniform excitation corporate feed network has multiple microstrip segments with different impedances, impedance matching is crucial to achieving better radiation and resonance characteristics. While designing a non-uniform excitation array, the major problem one can encounter is creating an efficient feed network with microstrip segments that could be realizable using available fabrication techniques.

As we know, the width of the microstrip segment to be created will become un-realistic if the impedance of the microstrip is more than 200 $\Omega$. To avoid this complexity, after every stage power division, authors used Quarter Wave Transformers (QWT’s) appropriately to scale down the feed point impedances for achieving better impedance matching. The feed network developed to create a 1x4 Dolph-Chebyshev excitation array with feed point impedances 50$\Omega$, 100$\Omega$, 66.69$\Omega$ and 33.99$\Omega$ is shown in figure 1.

2D surface current distributions were studied at the desired 28 GHz and 40 GHz resonant frequency. Based on the analysis made out of surface current distribution plots, defect on the ground plane is introduced by creating six circular rings, each 0.5 mm width. The geometry and specifications of initial antenna array and the defected ground antenna array are depicted in figure 2 and figure 3 respectively.

![Figure 1. Adopted feed with Non-uniform excitation (Dolph-Chebyshev distribution)](image)

![Figure 2. Simulated antenna array without DGS (a) Top view (b) Bottom view](image)
The physical dimensions of the patch element, DGS and feed network are presented in table 1.

| Parameter | Size (mm) | Parameter | Size (mm) |
|-----------|-----------|-----------|-----------|
| Lg        | 16.74     | Wg        | 31.56     |
| Lp        | 3.1       | Wp        | 4         |
| W1        | 1.33      | W2        | 2.41      |
| W3        | 3.37      | Wf1       | 1.93      |
| S         | 3.61      | Rout      | 1.581     |
| L1        | 1.85      | L2        | 2.42      |
| L3        | 1.33      | L4        | 1.93      |
| L5        | 3.5       | L6        | 3.37      |
| L7        | 0.62      | Lf1       | 3.61      |
| Rin       | 0.581     |           |           |

3. Results and Discussion

Simulations results are plotted using HFSS Ver. 18.2. The $S_{11}$ and 2D radiation patterns are analysed to understand the resonance and radiation behaviour of the designed antenna arrays. From the results presented in figure 4, one can make out that both designs reveal dual-band nature. The antenna array without DGS is providing a -10 dB bandwidth of 3.78 GHz and 2.21 GHz bandwidth at 28 GHz and 40 GHz band respectively. After introducing the defects in the ground plane the current distribution is changed at 28 GHz, as a result of this, the bandwidth is increased from 3.78 GHz to 6.13 GHz, maintaining same bandwidth at 40 GHz with a resonant frequency shift closer to desired 40 GHz.

Figure 4. Comparison of Reflection coefficient
Figure 5. Current density plots (a) at 28 GHz without DGS (b) at 40 GHz without DGS (c) at 28 GHz with DGS (d) at 40 GHz with DGS
Figure 5 depicts the surface current densities at 28 GHz and 40 GHz mm-wave frequencies. From the figure, one can observe that the concentration of current near the T junction of 100 Ω and 50 Ω microstrip line segments of feed network without DGS is more at 28 GHz compared to that at 40 GHz. The defect created in the antenna array improved the current distribution at the junction and enhanced the -10 dB bandwidth at 28 GHz from 3.78 GHz to 6.13 GHz.

![Figure 5](image)

**Figure 5.** The concentration of current near the T junction of 100 Ω and 50 Ω microstrip line segments of feed network without DGS is more at 28 GHz compared to that at 40 GHz.

The 2D radiation patterns of antenna array without DGS and with DGS are compared at 40 GHz, and the same is plotted in Figure 6. For φ = 0° and 0 ≤ θ ≤ 360° (E plane pattern), the plot shows almost omnidirectional and for φ = 90° and 0 ≤ θ ≤ 360° (H Plane pattern) shows the significant power concentration between 25° and 120°. From the traces of E plane and H plane radiation patterns, one infer that antenna array with DGS is having the highest peak gain of 8.88 dB.

![Figure 6](image)

**Figure 6.** Two dimensional radiation patterns at 40 GHz (a) E Plane (φ = 0°) (b) H Plane (φ = 90°)

Figure 7 shows the 2D radiation patterns at 28 GHz. There is not much change seen in the E plane radiation pattern at 28 GHz, compared to the radiation pattern plotted at 40 GHz. But one can observe a significant change in the H plane radiation pattern of 28 GHz, compared to 40 GHz radiation pattern.

![Figure 7](image)

**Figure 7.** Two dimensional radiation patterns at 28 GHz (a) E Plane (φ = 0°) (b) H Plane (φ = 90°)
This is due to change in the current density at 40 GHz caused by the creation of defects on the ground plane of the antenna array. The observed peak gain at 28 GHz is 7.77 dB. The simulation results of antenna array without DGS and antenna array with DGS are contrasted and presented in Table 2.

Table 2. Comparison between the antenna arrays

| Parameter          | With DGS | Without DGS |
|--------------------|----------|-------------|
|                    | 40 GHz   | 28 GHz      | 40 GHz   | 28 GHz   |
| $S_{11}$ (dB)      | -11.41   | -13.14      | -7.58    | -13.46   |
| Gain (dB)          | 8.88     | 7.7         | 7.89     | 7.77     |
| BW (GHz)           | 2.21     | 6.13        | 2.21     | 3.78     |
| Overall Size (mm)  |          | 31.56 x 16.74 |         |          |

Comparing the tabulated results, one can observe that the antenna array with DGS shows larger -10 dB bandwidth at 28 GHz, without changing the bandwidth at 40 GHz. At the same time, the DGS used in the array helped to improve the gain by almost 1 dB at 40 GHz maintaining the same overall size.

4. Conclusions

A dual-band low profile antenna array is designed to operate at 28 GHz and 40 GHz. DGS method is adopted to improve the gain at 40 GHz and bandwidth at 28 GHz. Table 3 presents the comparison table of antenna arrays developed by the authors with closely matched antenna arrays available in the literature. Observing Table 3, one can infer that the proposed antenna arrays in this paper are smaller in size compared to identical antenna arrays exist in the literature. Among the antenna arrays reported, the proposed antenna array with DGS is exhibiting larger bandwidth. Since the proposed antenna arrays are having sound radiation and resonance characteristics at 5G mm-wave frequency bands, these antennas can be used for applications at 28 GHz and 40 GHz mm-wave wireless bands.

Table 3. The comparison of proposed work with similar works reported in the literature

| Reference cited | $f_r$ (GHz) | $\varepsilon_r$ | $S_{11}$ (dB) | Gain (dB) | BW (GHz) | Overall Size (mm) |
|-----------------|-------------|-----------------|---------------|-----------|-----------|--------------------|
| With DGS        | 28          | 2.2             | -13.14        | 7.7       | 6.13      | 31.56 x 16.74 x 0.787 |
|                 | 40          |                 | -11.41        | 8.88      | 2.21      |                     |
| Without DGS     | 28          | 2.2             | -13.46        | 7.77      | 3.78      |                     |
|                 | 40          |                 | -7.58         | 7.89      | 2.21      |                     |
| [3]             | 28          | 2.2             | -16.37        | 17        | 0.308     | 30.65 x 39.3 x 0.127 |
| [4]             | 28          | 2.2             | -31.61        | 7.18      | 4.127     | 35 x 25 x 1.57      |
|                 | 38          |                 | -31.06        | 10.1      | 3.152     |                     |
| [8]             | 25          |                 | -45           | 8.6       | 0.66      |                     |
|                 | 28          |                 | -25           | 10.2      | 0.76      | 25.9 x 27.6 x 7.078 |
|                 | 38          |                 | -43           | 6.5       | 1.02      |                     |
| [9]             | 28          | 4.5             | 8.85          | 5.47      | 36 x 74 x 1.6 |
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