Dual-Band 28/38 GHz Inverted-F Array Antenna for Fifth Generation Mobile Applications †

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Abstract: The development of 5G (fifth generation) mobile communication systems was initiated to meet the expected need for higher data rates. In this article, a new 28/38 GHz dual-band “inverted-F” array antenna for 5G applications is proposed. This antenna can be integrated in OLEDs (Organic Light Emitting Diodes) panels which can be used both for lighting or display. This 5G antenna, composed of 32 elements, has the advantage of a dual-band and compact structure. Each element of the array antenna has the shape of an “inverted-F” antenna. This array antenna can cover the 28 GHz band (27.94–28.83 GHz) and the 38 GHz band (37.97–38.96 GHz) with mutual coupling between the elements less than −35 dB. The characteristics of the end fire radiation beams were obtained by employing an array of 32 “inverted-F” antenna elements on the upper and lower portions of the PCB (Printed Circuit Board). The suggested design has a gain of approximately 16.52 dB at 28.38 GHz and 15.35 dB at 38.49 GHz, which is suitable for 5G mobile communications.

Keywords: antenna; array antenna; fifth generation; millimeter wave; OLEDs light sources

1. Introduction

Since the beginnings of consumer wireless telephony in the early 1980s with the first Generation “1G”, which gives the user the freedom to make and receive phone calls, mobile communication systems go through different evolution stages [1,2]. This development is mainly based on the increase in data transfer rate, which achieved 100 Mbit/s for fourth generation systems, and it can be improved to 1 Gbit/s. The goal for the fifth generation systems is determined to reach up to 10 Gbps and a latency of about 1 ms, which results in a reduction in the energy consumption [3].

The antennas for the fourth generation operate in the 0.5–3 GHz frequency band, while the antennas for the fifth generation operating in the 28 GHz and 38 GHz bands [4–6]. The new cellular technology uses the millimeter wavelength spectrum, which permits the use of larger bandwidths, wireless broadband access, the use of large numbers of antennas in the transmission and reception, and reduces the mutual coupling between the antennas [7]. For the spectrum of millimeter-wave, the use of antennas with high gain and directional radiation patterns is necessary [8].

For the mobile phone applications, the antennas must be compact, small size, with low SAR value and compatible with other RF components [9,10]. Therefore, the use of millimeter wave spectrum automatically reduces the electrical length of the antenna, which complicates task of this antenna design, and allows for the use of array antenna to improve the antenna gain to overcome excessive path loss in the millimeter wave band [11,12]. In addition, the dual band antennas solutions are desirable
for 5G applications. Several works of literature have proposed dual-band 28/38 GHz antennas for mobile phones through several techniques [13–22].

The aim of this article is to design a dual band patch array antenna, for 5G mobile phone communication, with: high gain, radiation pattern beams characteristics, wide bandwidth, and a simple geometry which is formed by using the “Inverted-F” element. To improve the antenna gain, the array antenna technique is applied and gives us gains of 16.52 dB at 28.38 GHz and 15.35 dB at 38.49 GHz for an array of 32 elements.

2. The Single Element “Inverted-F” Antenna

2.1. Antenna Geometry

The aim is to design an antenna with a high gain and a directional radiation pattern for mobile phones in next generation mobile communication. Since the millimeter wave band is reserved for future 5G systems, the antennas that operate in this band are of small sizes. The dimensions and the geometry of the antenna are given in Figure 1. This antenna is designed on a FR4 substrate with permittivity \( \varepsilon_r = 4.4 \), loss tangent \( \tan \delta = 0.025 \) and thickness \( hs = 0.2 \) mm. The ground plane dimensions are 5.5 \( \times \) 4 mm\(^2\). To obtain two distinct operating bands, the antenna has the shape of an “inverted-F”. The configuration of the “inverted-F” antenna comprises two L-strip branch: one for the 28 GHz band and the other for the 38 GHz band. The parameter values of the antenna are shown in Figure 1. The antenna was designed and optimized using CST Microwave Studio.

![Figure 1. The geometry of the antenna: (a) ground plane, (b) bottom view and (c) side view.](image)

2.2. Parametric Study

To understand the operating behavior of the 5G antenna, a parametric study is performed by CST microwave studio. Figure 2 shows the effect of the variation of patch length \( L_p \) on the reflection coefficient of the antenna (\( L_p = 1.45 \) mm, 1.5 mm, 1.55 mm). This figure shows that the resonance frequencies for the two bands 28/38 GHz shift to lower frequency with increasing \( L_p \). The results of the reflection coefficient for the variation of patch width \( W_p \) (\( W_p = 1.65 \) mm, 1.7 mm, 1.75 mm) are shown in Figure 3. We notice, with increasing \( W_p \), the resonance frequencies in the two bands, 28/38 GHz, shift to lower frequencies.
2.3. Reflection Coefficient

The reflection coefficient for the single element of the 5G antenna is shown in Figure 4. The two operating bands of the antenna are obtained: the first band ($S_{11} < -6$ dB) from 27.94 to 28.83 GHz with a width of 890 MHz and the second band from 37.97 to 38.96 GHz with a width of 990 MHz. The two bands obtained cover millimeter-wave frequency bands for future mobile cellular devices.

2.4. Current Distribution

To understand the operating mechanism of the antenna, the surface current distribution at both operating bands was studied. The surface current distributions of the 5G antenna at 28.38 and 38.49 GHz are shown in Figure 5a,b, respectively.
2.5. Radiation Pattern

The 3D radiation pattern of the single element “inverted-F” antenna at 28.38 and 38.49 GHz are illustrated in Figure 6a and Figure 6b, respectively. The obtained results showed that the “inverted-F” antenna had a good end-fire radiation behavior and a gain of 6.22 dB at 28.38 GHz and 6.33 dB at 38.49 GHz.

3. The “Inverted-F” Array Antenna

3.1. The Antenna Array Geometry

The chosen configuration for the application is a 32 array element with identical elements. Figure 7 shows the geometry of the linear array with 32 elements of the “inverted-F” antennas. The 16 array elements are chosen to be placed in the top portion of PCB, while the other 16 elements are placed in the bottom portion of the PCB. For uniformly spaced linear arrays, the elements have 4 mm spacing between them (0.795λ at 28.38 GHz and 1.076λ at 38.49 GHz). The PCB size is 133 × 64 × 0.2 mm³. The array antenna has been designed, optimized, and simulated using the CST microwave studio.
3.2. The S-Parameters of the Array Antenna

The simulated S-parameters for the array antenna are illustrated in Figure 8. From this figure, we can see that the array antenna exhibits good impedance matching in the 28/38 GHz frequency bands and the mutual-coupling characteristics between the elements are less than $-35$ dB.

3.3. The Cartesian Gains

The Cartesian gains of the array antenna in x–z plane are displayed in Figure 9. As illustrated, the array antenna has a good beam steering characteristic with end-fire mode and sufficient gains at different scanning angles.

A stable gain with a value of 16.52 dB (+10 dB compared to a single antenna element) at 28.38 GHz is observed in Figure 9a. Additionally, from Figure 9b, we notice that the antenna gain decreases with the increase in the angle; and it is about 15.35 dB in 0° (+9 dB compared to a single antenna element) at 38.49 GHz.
3.4. The Radiation Pattern of the Array Antenna

The beam steering characteristic of the simulated radiation patterns of the 5G antenna in different scanning angles (0° to 45°) is also studied. Figures 10 and 11 show the 3D radiation pattern beams of the array antenna at 28.38 and 38.49 GHz, respectively. The beam steering characteristic of the 5G antenna for plus/minus scanning angles are symmetric [16]. We observe, the array antenna has a good beam steering property which is highly effective to cover the range of ±45° [17].
4. Conclusions

In this paper, a new compact dual-band (28/38 GHz) “inverted-F” array antenna for the future fifth generation (5G) mobile networks have been demonstrated. The 5G antenna is worked in the 28 GHz mm-wave band (27.94–28.83 GHz) and the 38 GHz mm-wave band (37.97–38.96 GHz) with a bandwidth 890 and 990 MHz, respectively. Since the proposed antenna is of small size and simple geometry with the simplicity of reaching the desired frequency bands, it is easy to manufacture and integrate in the case of the OLEDs. The mutual-coupling characteristics between the elements are less than $-35$ dB. To improve the gain of the antenna, we used the antenna array technique. Therefore, we have reached a high gain of 16.52 dB in the first band and 15.35 dB in the second band. End-fire radiation beams were achieved by employing 32 elements of “inverted-F” antennas on the top and bottom portions of the OLEDs display. With 5G communications, the bandwidth and data rate will be higher, but the distance between receiver and transmitter will be shorter. This makes it necessary to multiply the antennas across an extended network, for example, such as the public lighting network. In this context, this antenna is a good candidate for 5G applications and can be integrated in OLED panels for display as well as in street lighting.

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