Broadband Printed-Dipole Antenna for 4G/5G Smartphones

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Abstract. Nowadays, mobile communication systems are required to provide larger bandwidth and higher data rates to accommodate the increasing number of subscribers, and the vast amount of data handling. The fifth generation (5G) requires higher frequency bands as the sub-six and the millimeter bands. New designs for antennas are expected to fulfill these requirements in addition to covering the current mobile systems. Thus, there is an increasing demand to design antennas that cover both 4G and 5G bands for mobile communication systems. In this paper, a novel design based on monopole antenna of various shapes and dimensions is introduced. The single-element antenna yields an $|S_{11}|$ better than $-6$ dB over the operating frequency bands of (1.24 GHz - 2.64 GHz) and (3.34 GHz - 5 GHz) with gain and efficiency of 5 dBi and 80\% respectively. So, the proposed antenna covers 23 bands of the total (32) 5G NR bands in addition to 30 LTE bands.

Keywords: 4G LTE, 5G, Monopoles, Microstrip Antenna and Multi band antenna

1. Introduction
In the modern wireless communication systems, the data transmission rate has been one of the critical topics for the smartphones applications. 5G New Radio (NR) has become a hot spot in the field of mobile communications in order to meet the needs of high data rate and a better service quality for wireless applications such as 3D video streaming and ultra HD (UHD)[1]. The first commercialized 5G technology is expected to be release in the early 2020s. The microstrip antennas have been a perfect choice due to their attractive advantages and characteristics such as low profile, light weight, low fabrication cost, easy to integrate them with MICs or MMICs

In mobile communications, due to the rapid growth of the mobile users, the need for designing multi-operating band antennas in mobile terminal/handset has become a necessary requirement. The microstrip monopole antenna is one of the most suitable antenna for achieving wide operating bandwidth with omnidirectional radiation pattern [1] and compact size. There are several methods used in designing the monopoles such as inverted pi shaped, long L and short L monopole antenna [2-3], E shaped [4], Z shaped [5], T shaped [6-7] antennas and fork shaped monopole [8-10].
In this paper, a novel multi band antenna is obtained from the fork antenna in order to embed many monopoles in one design to cover as much 4G and 5G bands. The proposed antenna can cover the frequency bands from 1.24 GHz to 5 GHz except the bands from 2.3 GHz to 3 GHz in the 5G NR bands. The rest of paper is organized as follows; Section 2 includes the proposed antenna structure. Section 3 describes simulation and result analysis. Antenna fabrication and lab measurements are illustrated and discussed in Section 4. Finally, Section 5 provides the main conclusions of the presented work.

2. Proposed Antenna Structure

2.1. Conventional Antenna Designs
To commence the design of the antenna, the required bands for operation are identified. Single-band antenna is used to cover only one band, dual band antenna is used to cover two bands, and multi-band antenna covers more than two bands. Dual and multiband 4G antennas with different shapes were reported and tabulated in Table 1. It is noted that, bands are achieved by having slots with different shapes in the ground of the antenna. The Z-shaped patch antenna with I-slot is adopted [5] to cover S and C bands, which investigates the usage of single element to resonate in two different bands using I-slot. A T shaped antenna [6] is designed with a U slot in the ground plane. In addition, an inverted L shaped patch antenna [6] is designed using a U slot in the ground plane to get a better performance for the antenna. A multi-band and multi-mode T shaped slot antennas [7] are proposed. However, when changing the position of the slot, an antenna with different mode is obtained.

| Ref. | Shape                | Band Type | Operating Band (GHz)                  | Total Size (mm) |
|------|----------------------|-----------|---------------------------------------|-----------------|
| [2]  | Inverted Pi          | Dual      | LTE 42,43 and LTE 46                  | 150x80x0.8      |
|      | Long L               | Single    | LTE 42,43                             |                 |
|      | Short L              | Single    | LTE 46                                |                 |
| [3]  | Inverted L           | Single    | 3.4-3.8                               | 140x70x0.8      |
| [4]  | E-shaped             | Triple    | 8.80-13.49                            | 15x21.7x3.2     |
| [5]  | Z-shaped with I-slot | Dual      | S and C Band                          |                 |
|      | T-shaped             | Single    | 5.1-5.8                               |                 |
| [6]  | T-shaped with U-slot | Dual      | 5 & 7.2 bands                         | 38.04x29.44     |
|      | Inverted L shaped    | Single    | 4.6-5.8                               |                 |
|      | Inverted L with U-slot | Dual        | 5.2 & 7.4 bands                      |                 |
| [7]  | T-shaped slot        | Multi     | LTE 42,43 and LTE 46                  | 150x80x0.8      |
| [8]  | Fork Antenna         | Dual      | 2.4-2.48 and 3.1 -10.6 GHz            | 50x66x1.67      |
| [9]  | Fork Antenna         | Triple    | 2.4-2.48,3.1-10.6 GHz GSM band at 1.8 GHz | 42x24x1.6 |
| [10] | Fork with T shaped open slot | Multi | 1.21-1.29, 3.65-3.94 and 5.0-5.20 GHz | 48.6x57.2x1.6   |

2.2. The Proposed Antenna Configuration

The structure and the physical dimensions of the proposed antenna are depicted in Figure 1. The FR4 substrate is used as a base for the System Circuit Board (SCB), FR4 has the following specifications: height, h = 0.8 mm, relative permittivity, εr = 4.5, loss tangent, δ = 0.02 and the thickness of the upper and lower conducting layers is 0.035 mm. The SCB has a dimension of 150 x 80 mm2, which is compatible with a 5.7-inch smartphone. The proposed antenna is fed by a 50 Ω microstrip line. A 50 Ω Sub Miniature Version A (SMA) connector is connected to the 50 Ω microstrip transmission line.
Adopting the transmission line model, and taking into account the fringing effects, the resulting effective permittivity is \( \varepsilon_{\text{eff}} = 3.139 \). Figure 1(a) shows the front view of the complete SCB, whilst figure 1(b) shows the detailed proposed antenna configuration. The monopoles are etched on the top layer of the substrate. There are four monopoles that are marked (ABCD), (ABE), (AFGH) and (AFGIJK). The feedline to the monopoles is located in the upper layer, and there are two open slots placed in the ground plane. Table 1 lists the dimensions of the designed antenna.

Figure 1. The Proposed Antenna: (a) Top view of the SCB, (b) Antenna configuration

Table 2. The Values of the lengths of the Monopoles

| Symbol | Length (mm) | Symbol | Length (mm) | Symbol | Length (mm) |
|--------|-------------|--------|-------------|--------|-------------|
| L1     | 7           | L2     | 2           | L3     | 1           |
| L4     | 1           | L5     | 1.5         | L6     | 8           |
| L7     | 2.5         | L8     | 3.5         | L9     | 10.5        |
| L10    | 4           | L11    | 3           | L12    | 2.2         |
| L13    | 5           | L14    | 6           | L15    | 13          |
| L16    | 3           | L17    | 5.7         | L18    | 8.7         |
| L19    | 3           | L20    | 3           | Wf     | 1.5         |
| Wm     | 0.5         |        |             |        |             |
3. Simulation and Result Analysis

3.1. Overview of Resonant Modes

To illustrate the operating principle of the proposed antenna, each part of the antenna is investigated separately. In order to interpret the effect of each monopole, a parametric study will be done by disconnecting all the monopoles except one for each study by taking in a count the effect of the other parasitic monopoles. The antenna is simulated using the CST studio suite 2019. The first case is ABE path with open slot in the ground. The second one is the ABCD monopole, then the AFGH monopole and finally, the AFGJK monopole.

In the first case, disconnect all dipoles except ABE as shown in figure 2(a). Figure 2(b) shows the current distribution on the monopole ABE. Figure 2(c) depicts the simulated reflection coefficient curve $|S_{11}|$, it is shown from figure 2 that the monopole ABE excite open slot at 4.7 GHz which represents N79 band, that is measured at 4.7 GHz.

![Monopole ABE](image)

**Figure 2.** Monopole ABE, (a) ABE arm only connected (b) current distribution, (c) $S_{11}$ curve.

In the second case, by referring to figure 1, disconnect all dipoles except ABCD, then the ABCD monopole is an extension of the ABE monopole which serves the purpose of keeping the antenna size in the smallest side to fit into the commercial smart phones. Figure 3 demonstrates the implementation of the monopole ABCD, the current distribution is measured at 3.9 GHz and the $S_{11}$ curve in figure 2(c) shows that the length of ABE is resonating at the operating frequency band 3.28 GHz - 4.64 GHz. This monopole covers N78 band, LTE band 22, LTE band 43 and LTE band 48.
In the third case, the AFGH monopole arm was implemented. It covers the operating bands (1.46 GHz - 1.69 GHz) and (2.746 GHz - 3.63 GHz) as shown by the $|S_{11}|$ curve in Figure 4. The current distribution shows that the open slot and the AFGH monopole resonate at 1.46 GHz & 3.2GHz, respectively, as shown in Figure 4 (a) and (b).

Finally, the AFGIJK monopole is implemented, figure 5(a) shows the current distribution at 3.25 GHz and Figure 3(b) illustrates that this monopole operates in the 2.85 GHz - 3.503 GHz band.
Figure 5. The Monopole AFGIJK: (a) current distribution at 3.25 GHz and (b) S11 curve. The total performance of the proposed antenna is illustrated in figure 6.

![Figure 5](image_url)

Figure 6. S11 of the proposed antenna.

3.2. Radiation Pattern of the Proposed Antenna

The radiation pattern of the proposed antenna is shown in figure 7 for the frequencies of 1.45, 2.5 and 3.8 GHz. The radiation pattern is illustrated in the H-plane (x-y plane), E-plane (y-z plane) and x-z plane, in addition to a 3D pattern at each frequency.

![Figure 7(a)](image_url)

Figure 7(a). Simulated radiation pattern at $f = 1.45$ GHz

![Figure 7(b)](image_url)

Figure 7(b). Simulated radiation pattern at $f = 2.5$ GHz

![Figure 7(c)](image_url)

Figure 7(c) Simulated radiation pattern at $f = 3.8$ GHz
3.3. Gain of the proposed antenna

Figure 9 shows the simulated gain of the proposed antenna versus frequency. It is clear that the gain of the proposed antenna ranges from 4.25 to 6 dBi over the operating band of (1.4 GHz - 2.64 GHz) and (3.32 GHz - 4.64 GHz). Figure 9 shows the simulated antenna efficiency of the proposed antenna in the same frequency range. The efficiency ranges from 70% to 90%.

![Figure 8: Antenna gain versus frequency.](https://example.com/figure8.png)

![Figure 9: Antenna efficiency versus frequency.](https://example.com/figure9.png)

4. Measurements of the Proposed Antenna

The proposed antenna is fabricated and an SMA connector is connected to the port of the microstrip feed line as shown in figure 10. The FR4 substrate, specified in Section 2, is used as a base for the System Circuit Board (SCB). The reflection coefficient of the realized antenna has been measured using ROHDE & SCHWRZ 4 port Vector Network Analyzer (VNA) up to 22 GHz. The measured $S_{11}$ parameter is compared to those obtained by the CST simulator. Figure 11 shows a comparison of both the simulated and measured $S_{11}$. It is noted that the proposed antenna exhibits the bandwidth from 1.4 to 2.64 GHz and from 3.32 to 4.64 GHz. This bandwidth achieves the covered LTE 4G and 5G NR bands.

![Figure 10: The multi-band fabricated antenna, (a) Top View, (b) Bottom View.](https://example.com/figure10.png)
5. Conclusion

In this paper a novel antenna has been introduced that operates for both 4G/5G mobile communication systems. The antenna is simulated and fabricated so the total dimension of the SCB is 150 x 80 mm$^2$ that would fit in the commercial cellular phones. The antenna occupies the top corner of the substrate and has a dimension of 11.7 x 15.9 mm$^2$. The antenna is constructed of four monopoles of various shapes and dimensions, a stub and two open slots itched in the ground plane. Each part of the antenna contributed to different frequency bands. This single element antenna structure covers frequency ranges from 1.4 to 2.64 GHz and from 3.32 to 4.64 GHz, which is equivalent to 23 bands of the total (32) 5G NR bands and 30 bands of the total (76) LTE bands. The antenna has an efficiency of 80% and a gain of 5 dBi. The proposed antenna element satisfies the desired design specifications in addition it has a small area, so it can be arrayed to form Multi Input Multi Output (MIMO) antenna system which represents one of the key features of 4G/5G air interface.

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