A Dual-Polarized MIMO Array Antenna System for Future Smartphone

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Abstract. In this paper, a dual-polarization four antennas Multiple Input Multiple Output (MIMO) scheme is proposed. The four elements are arranged over a surface area of 67×139mm² printed circuit board (PCB) using dielectric substrate FR-4 with epsilon 4.4 and thermal conductivity 0.025. A circular slot radiator is etched in ground plane in order to improve the radiation characteristics. To mitigate the mutual coupling in the proposed MIMO scheme, two rectangular parasitics with one open rib are embedded across square slot radiator. The proposed single antenna model covers a frequency range of 5.81-6.66 GHz at -10dB impedance bandwidth. However, the bandwidth is raised up to 1.47 MHz (5.48-6.95) GHz at -6dB. The results show that -20 dB return losses can be obtained, while -45 dB isolation was achieved for a dual microstrip line. The proposed antenna can be integrated with new smart-mobile devices for future 5G wireless communications.

Keywords. Polarization, MIMO, dual polarized antenna, linear polarization capacity, SMA connector.

1. Introduction
In the late on the 2000s, the fourth generation (4G) mobile system was introduced and was all Internet Protocol (IP) which based network system. It aims to provide high capacity, high quality, security, high speed and low-cost services for voice and data services, multimedia and internet over IP. As a result, for huge growth of devices number which demanding internet-access that would require wide bandwidth in order to operate in normal state that 4G cannot cut it anymore, therefore fifth-generation (5G) have been introduced. It is critical issue in term of speed, response time, energy efficiency and network reliability. The high frequencies concerned with short wavelengths, and for millimeter waves which have range of 1 mm to 10 mm. 5G is being related to the use of millimetre-wave by allocating more bandwidth to arrive faster with higher quality video and contain multimedia and services. However, millimeter wave
has easily absorbed by trees, gasses in the air, nearby buildings and dust particles so that the main challenges in the millimetre-wave bands are the impairment factors. To address this problem multiple-input multiple-output (MIMO) are used to compensate the great attenuation facing 5G band frequencies. MIMO system has many facilities like improvement capacity, increasing data rate, mitigate high fading and time-variant of wireless channel. MIMO antennas having a good radiation pattern when it deals with the desired diversity which can be investigated by spatial diversity, beam diversity and polarization diversity [1]. The last one can be achieved simply with a low-profile mobile system that means each pair of antennas are orthogonally polarized when having the same gain in the assumed directions and at the same time. Polarization diversity can be doubled the frequency spectrum which can achieve the desired enhancement in capacitance of wireless spectrum [2]. As it is known, MIMO technique with high number of antennas called recently as Massive antennas MIMO (MA-MIMO) system has capability of dynamic directivity, which is preferred diversity to improve performance of the millimeter waves. However, the main challenge of MIMO system is the mutual coupling problem when the distance between antenna is inevitably [3,4]. In general, mutual coupling means that the current which induced one of the antenna elements leading to produce a voltage at the neighbouring antenna element’s terminal [5]. If the problem is solved towards increasing the distance separated between MIMO elements, this will lead to enlarge the system size, which is not preferred solution. This problem was addressed by many methods, for examples, neutralization lines which means neutralization line (NL) connected in between two antennas [6, 7]. Also decoupling network is a transmission line section with stubs which provide more signal path between the array elements that effectively cancels the external coupling between them [8,9]. In addition, electromagnetic bandgap structures (EBG) which artificial periodic structures that assist the propagation of electromagnetic waves in a specified band of frequencies for all incident angles and all polarization states [10,11]. On the other hand, ground plane modifications which concern geometry modifications of the antenna structure in the context of miniaturization [12, 13]. Another solution is metasurface walls which eliminate of surface waves by using corrugations along the sidewalls of the antenna [14,15]. Characteristic modes which mean the current modes that correspond to the eigenvectors of a particular weighted eigenvalue equation involving a generalized impedance matrix of the conductor. Hence, characteristic modes can be used to expand the total current on the conductor surface [16, 17]. The researchers in [18] proposed a design with only two elements to improve isolation. But such solution with this limitation will lose us the diversity advantages of MIMO system. Accordingly, the best design of MIMO system will be avoided us many challenges faced the band frequencies. For example, [19] proposed a multiband ten antenna-array with sub-6 GHz for 5G smartphone applications. Development the antenna technology is a key feature to get a good design of polarization technique to improve the communication system. The researcher of [20], utilized the polarization by proposed four resonator slot antennas each element have a dual-polarized orthogonally feeding lines for 5G smart-phone applications. Accordingly, a good design for MIMO system which the main object of this paper will offer good performance, high capacity with low profile and complexity.

2. Dual Polarization

The basic characteristics of polarization diversity are that multiple antenna output experience different signals result in different spectrum and these signals is correlated partially. The polarization diversity allows transmitting data stream with the same frequency band which arise the spectrum efficiency. As it is known there are two types of polarization namely linear polarization which is either horizontal or vertical, by means that one of the two signals are in phase while the other is 90° out of phase. Another type of polarization is circular polarization, clockwise or anticlockwise by ±45°. Also, each previous main type (orthogonal and circular) of polarization have the same capacity in MIMO system [21]. The general derived formula of capacity as [22, 23]:

$$C = \log_2 \det [ I + \left( \frac{r}{\eta} \right) HH^\dagger ]$$

Where I is \((n_t \times n_t)\) identity matrix, H is the \(n_r \times n_t\) channel matrix, \(H^\dagger\) is the transpose conjugate and \(r\) is the SNR. For a general MIMO system, the number of antennas is a critical issue for system capacity. Channels deal with MIMO have composite from line of sight (LOS) and non-line of sight (NLOS) matrix.
component, the ratio of the characteristic of LOS is accomplished by Ricean (K_factor). In the dual-polarization, sometimes it is taken into consideration the angle between the antennas of transmitter and receiver by a complex matrix, which can be calculated by [24],

\[
H_u = \begin{bmatrix}
e^{0.75 j \pi} & e^{-0.25 j \pi} \\
e^{0.25 j \pi} & e^{0.25 j \pi} \\
e^{0.75 j \pi} & e^{-0.25 j \pi}
\end{bmatrix}
\]

With a small distance most of LOS conditions, according to the dual-polarized antenna elements, the \( H_u \) rank can be improved the capacity of the wireless system. Depending on LOS conditions, although the antenna element numbers increased the capacity with high K_factor will not be increased unless polarization states increased [24].

3. Design of The Proposed System

In this research, four antenna elements are arranged in a proposed manner for the purpose of smartphone applications operated in a sub-band of 5G. Each one has a pair of orthogonally ports in order to cover all directions of Printed Circuit Board (PCB) unit.

3.1. The Design of Single Element

The single element consists of dual-polarized rectangular microstrip feeding-line 50Ω with a size of (3*9) mm² in the upper layer. As shown in Fig. 1(a), in the same layer of the feeding lines, there are two annular rectangulars each one opened from one of its ribs and embedded over a circular slot etched in the ground layer. The inner and outer radiuses of circular slot are \( r_1 \) and \( r_2 \) respectively. All the rest parameters of proposed single elements shown in Fig. 1, are listed in Table 1. The upper and ground layers are separated by FR-4 (lossy) with epsilon 4.4, thermal conductivity 0.025, and height of 1.6mm.

![Figure 1. Single Element Antenna, (a) Front View, (b) Back View, and (c) Side View.](image)

Table 1. Parameter Values of The Antenna Design.

| Parameter | Value (mm) |
|-----------|------------|
| \( W_s \) | 25         |
| \( h_s \) | 1.6        |
| \( L_m \) | 9          |
| \( W_m \) | 3          |
| \( C_1 \) | 2.5        |
| \( C_2 \) | 5          |
| \( C_3 \) | 0.75       |
The simulation result for S-Parameter of the model is shown in Fig. 2, which shows that return losses at resonance frequency 6.28 GHz. The achieved bandwidth is 0.85 GHz (5.81-6.66 GHz) at -10 dB while a good mutual coupling for the polarized ports can be obtained at -45 dB.

![S-Parameter of Single Antenna Element](image)

**Figure 2.** S-Parameter of Single Antenna Element.

Figure 20 illustrates the practical resultant VSWR, while the ideal VSWR was less than 2 [25].

![VSWR for Single Element](image)

(a) (b)

**Figure 3.** VSWR for Single Element, (a) Port1, and (b) Port2.

Figure 4 displays the 3D view dumbbell-shaped radiation patterns for each port in single antenna element at 6.28GHz which can cover the top and bottom of antenna side. They have a different polarization and similar radiation pattern performance with gain of 5.6 dBi and 5.59 dBi for port 1 and port 2 respectively.

![Radiation Patterns](image)

(a) (b)

3.2. The Proposed Model

In this research, four elements of dual-polarization are arranged with a PCB for smartphone applications in the range of 5G sub spectrum. The proposed model is applied in a method as shown in Fig. 5 to achieve a flexible antenna pattern which responded for all direction applications. The PCB is an FR-4 (lossy) dielectric with a dimension 67×139 mm², epsilon 4.4 and 0.025 for thermal conductivity.
Figure 5. Smartphone Antenna System (a) Front view, and (b) Back view.

The integrated four antennas are combined in simulation for different PCB dimensions and they are studied in Fig. 6.

Figure 6. Different S-Parameter Results with a Dimension of (a) 70×145mm², (b) 75×145mm², (c) 71×150 mm², and (d) 75×155mm².

In this research, an optimum PCB dimension of 67×139 mm² is obtained by trying many other numbers (four examples are illustrated in Fig. 6). The simulation results of proposed array antennas when integrated with such PCB are shown in Fig. 7. The results of reflection coefficient $S_{11}$ and mutual coupling $S_{mf}$ for all ports excited simultaneously confirm that the resonance frequency is obtained at 6.28 GHz. Also, 800 MHz bandwidth between 5.8 and 6.6 GHz is achieved at -20dB, while the VSWR is slightly less than 2 as it is clear from Fig. 7 c.
Figure 7. System Antenna Array (a) Snm, (b) Snf and (c) VSWR.

The side view of the radiation pattern for each port is illustrated in Fig. 8 which confirm that each port can be covered an accepted size with suitable gain values for smartphone 5G applications.

Figure 8. Radiation Patterns for Each Port in System Antenna with Gain Value.

As compare the currently results of this research with previously research In the same field, it is clear that reference [20] which achieve a bandwidth 600 MHz at -10dB while the current research got 850 MHz at -10 Db. Also, the previous proposal operated at sub-6 band while the current proposal operates with C-band. As is worth mentioning, all simulations are applied for each port with SMA input connector with inner radius 0.65 mm and outer radius 2.25 mm as shown in Fig. 9, teflon with epsilon 2.1 used between them as a dielectric.
In order to realize such model fabrication, Fig. 5 illustrated the schematic of the proposed MIMO system with the mentioned SMA. Figure 10 shows the overall of 2D view of the radiation pattern of H-field which illustrates that the proposed scheme is in omnidirectional shape with lobe has angular width 14.2 deg. On the other hand, the 3D view of radiation pattern is covered over all of the PCB with H-max -22.3 dB and -5.51 dBi of gain.

**Figure 10.** MIMO Radiation Pattern (a) 2D and (b) 3D.

### Conclusion

In this research, a dual-polarization four elements MIMO system has been presented using CST software. A rectangular area of $67 \times 139$ mm$^2$ is used to implement four elements closed to each corner of the PCB with a two SMA connector for each one. The simulation results confirmed that the proposed model covered a quite good spectrum impedance bandwidth of around 850 MHz extended from 5.81 to 6.66 GHz. The mutual coupling matches the $S_{nn}$ response in the same 6.34 GHz resonance frequency. The proposed smartphone MIMO scheme showing a resonance frequency 6.25 GHz and covering a bandwidth of 700 MHz (5.9-6.6) GHz. It provides a suitable radiation pattern covering mostly all 3D space. We believe that such prototype is suitable for smartphone 5G applications.

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