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Dual-Band MIMO Circular Patch Microstrip Antenna (CPMA) with Low Mutual Coupling for 5G Communication System

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This paper proposes a MIMO circular patch microstrip antenna (CPMA) operating at resonant frequencies of 3.5 GHz and 6 GHz for 5G communication systems. The proposed antenna is designed using RO-5880 substrate with a dielectric constant (ε_r) of 2.2, a thickness (h) of 1.58 mm and a loss tan (tan δ) of 0.0009. The dual band characteristic is obtained by placing the slot in the center of the CPMA while the inset feeder is used to control the reflection coefficient. Furthermore, mutual coupling reduction is obtained by controlling the distance between the antennas when configured in MIMO. Based on the simulation results, the proposed antenna produces excellent performance with reflection coefficient ≤ -10 dB and mutual coupling (MC) ≤ -20 dB at resonant frequencies of 3.5 GHz and 6 GHz. This research is very useful and can be recommended as a receiving antenna for 5G communication system.

Keywords: Dual-band, Circular patch, Microstrip antenna, MIMO, 5G.

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1. INTRODUCTION

The 5G communication system requires high capacity to be able to serve an increasing number of users, especially nowadays where internet users are growing rapidly. Multiple Input Multiple Output (MIMO) is one of the solutions to increase the capacity of the communication system [1]. In addition, the allocation of spectrum and frequency is very important so that the communication system can run effectively [2]. Based on [3-5], one of the recommended frequencies for 5G communication systems is in the range below 6 GHz, including 3.5 GHz and 6 GHz. Furthermore, antennas with high performance are needed to be able to transmit information from senders and receivers, especially for 5G communication systems. One of the recommended antennas is the microstrip antenna which has the advantage of having a low profile, low cost, and excellent performance to operate at high frequencies [6-8]. The development of microstrip antennas for 5G communication systems has been widely described in previous studies [9-13].The previous research presented [14] proposed a CSRR microstrip antenna that operates for C-band (4.2, 7.6 GHz), 5.5 (HYPERLAN) X-band (9.7 and 11.4 GHz) and Ku-band (13.9 GHz) while the proposed research [15] multiband microstrip antenna for WLAN/WiMAX using CPW-Fed. However, the two previous studies cannot be used for MIMO communication systems because they only consist of a single patch. Another study [16] proposed a MIMO array antenna for ISM/5G NR/WLAN at a resonant frequency of 1.7 GHz and 3.5 GHz with low mutual coupling. However, the proposed resonance frequency does not meet the criteria of a 5G communication system where the recommended resonance frequencies are 3.5 GHz and 6 GHz. This paper provides a solution by proposing a MIMO microstrip antenna which has dual band characteristics and low mutual coupling. The proposed antenna has a circular patch operating at f_{r1} = 3.5 GHz and f_{r2} = 6 GHz with a reflection coefficient (S_{11}) of ≤ -10 dB and mutual coupling (S_{21}) of ≤ -20 dB. In order to achieve the dual-band characteristic, a slot loading technique is proposed while the inset feed is used to control the S_{11} of the antenna. Furthermore, low mutual coupling is obtained by controlling the distance between the antenna patches (d). The main contribution of this paper is to produce a MIMO microstrip antenna with dual-band characteristics and low mutual coupling so that it can be recommended as a receiving antenna for 5G communication systems.

2. ANTENNA DESIGN

2.1 Development Model of MIMO Dual-Band CPMA

The proposed antenna is designed using RO-5880 substrate with a dielectric constant (ε_r) of 2.2, a thickness (h) of 1.58 mm and a loss tan (tan δ) of 0.0009. The development model of the proposed antenna is shown in Fig. 1(a), Fig. 1(b), Fig. 1 (c) and Fig. 1 (d), respectively. The structure of the antenna consists of a patch made of cooper which functions as a radiator while the ground plane is used as the ground for the antenna. The 1st model of the antenna is shown in Fig. 1(a) where the patch used is a circular shape connected to a microstrip line and a connector with an impedance of 50 Ω. Furthermore, an inset feed is proposed on the 2nd model of the antenna to control the S_{11} of the antenna as shown in Fig. 1(b). In the 3rd model of the antenna, slot loading technique is used to produce dual-band characteristics and control the resonant frequency of the proposed antenna as shown in Fig. 1(c). Finally, the 4th model of the antenna is shown in Fig. 1 (d) where the MIMO antenna consists of two ports separated by a distance of (d). It should be noted, the distance from (d) greatly affects the mutual coupling of the MIMO antenna.

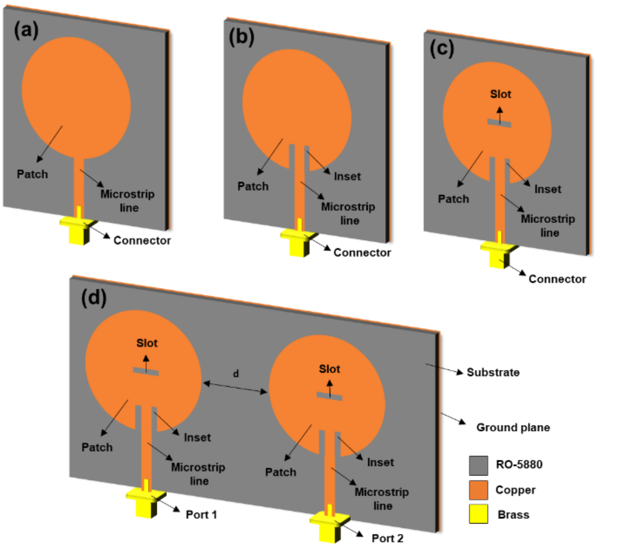

Fig. 1 – Development model of Dual-Band MIMO CPMA, (a) CPMA, (b) CPMA with inset feed, (c) CPMA with inset and slot, (d) CPMA with MIMO configuration

2.2 Dimension of CPMA

The dimensions of a microstrip antenna can be determined based on the resonant frequency and the characteristics of the substrate used. Furthermore, the dimensions of the CPMA are determined using the following equation [17]:

$$K = \frac{8.791\ x\ 10^9}{f_r\sqrt{\varepsilon_r}} \tag{1}$$

$$r = \frac{K}{\left\{1+\frac{2h}{\pi\varepsilon_r K}\left[ln\left(\frac{\pi K}{2h}\right)+1,7726\right]\right\}^{1/2}} \tag{2}$$

where $\pi = 3.14$, K is the logarithmic function of CPMA, and r is the radius of the antenna with a circular patch.

Based on Eq. (1) and Eq. (2) it can be concluded that the dimensions of the CPMA are greatly influenced by the resonant frequency and the characteristics of the substrate used. In other words, the dimensions of the antenna become more compact for high resonant frequencies. In this paper, the microstrip line is used as an impedance matching which functions to connect the antenna to the SMA connector which has an impedance of 50 Ω.

The dimensions of the microstrip line for an impedance of 50 Ω can be determined based on the following equation:

$$B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_{eff}}} \tag{3}$$

$$W_z = \frac{2h}{\pi}\left\{B - 1 - ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln(B-1) + 0,39 - \frac{0,61}{\varepsilon_r}\right]\right\} \tag{4}$$

where, B is the impedance constant for the microstrip line which is strongly influenced by the input impedance while W_z is the width of the microstrip line which serves to connect the antenna to the connector. Furthermore, the length of the microstrip line is determined by iteration using EM simulation.

3. RESULT AND DISCUSSION

3.1 Design and Simulation Process of CPMA

Based on equations (1), (2), (3) and (4) it is obtained that the radius (r) of the CPMA is 16 mm while the width of the microstrip line (W_z) is 2 mm. Furthermore, the dimensions of the ground plane are represented as W_g and L_g with a size of 50 mm × 50 mm. The overall dimensions of the CPMA are shown in Fig.2 (a).

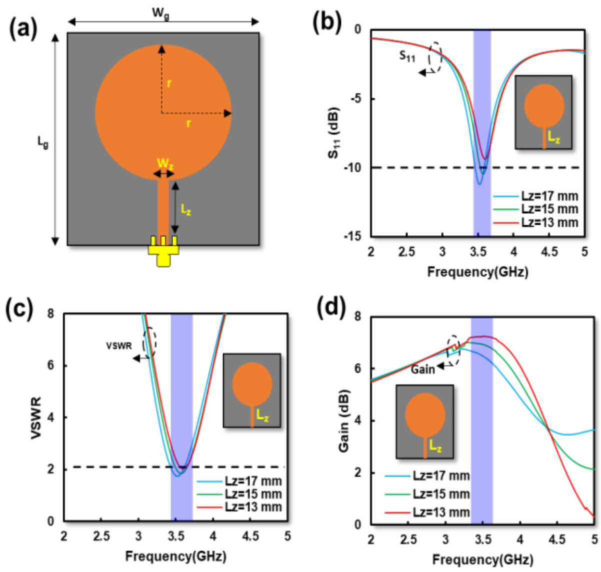

Fig. 2 – (a) Dimension of CPMA, (b) S_{11} of CPMA, (c) VSWR of CPMA, (d) gain of CPMA

Fig. 2(b) shows that the resonant frequency and S_{11} of the CPMA can be determined by controlling the dimensions of the length of the microstrip line (L_z). Besides that, VSWR and the impedance of the antenna are also affected by the length of the microstrip line as shown in Fig.2 (c) and Fig. 2 (d). From the optimization results using EM simulation it can be seen that the best performance of CPMA is obtained when $L_z = 17$ mm with S_{11} of – 11.28 dB , VSWR of 1.87 and gain of 6.72 dB with a resonant frequency of 3.55 GHz.

This indicates that the antenna has not worked optimally due to the impedance mismatch between the antenna and the connector. For this reason, further optimization is needed to improve the performance of the antenna.

3.2 Design and Simulation Process of CPMA with Inset

Furthermore, inset feeding is proposed to improve the performance of the CPMA as shown in Fig. 3 (a). The width and length of the feeding inset are represented as W_i and L_i, respectively. The function of the inset feeding is to determine the S_{11} of the CPMA by controlling the dimensions of L_i, while the dimensions of W_i are fixed, which is 1 mm.

Fig. 3(b) shows that S_{11} from CPMA improved after the inset feed was used. Similar findings were obtained for VSWR and impedance where both parameters can be determined by controlling the dimensions of L_i. The best performance is obtained when L_i = 4.8 mm with $W_i = 1$ mm where S_{11} for $f_{r1} = 3.5$ GHz is – 13.98 dB and $f_{r2} = 6$ GHz is – 23.37 dB while for VSWR are 1.58 and 1.21 as shown in Fig.3 (c), respectively. In addition,

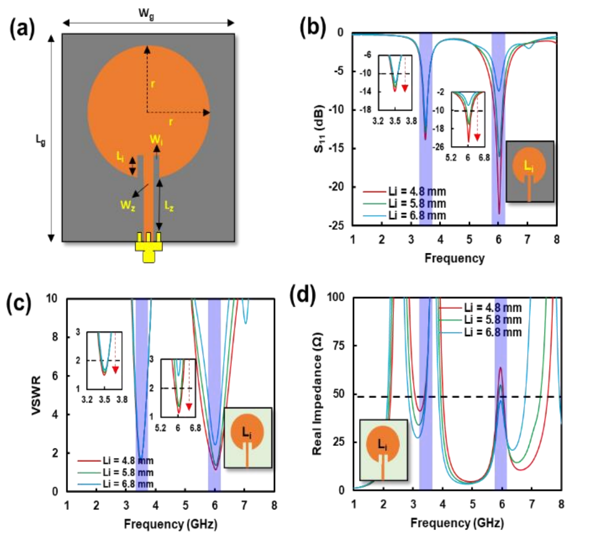

Fig. 3 – (a) Dimension of CPMA with inset feed, (b) S_{11} of CPMA with inset feed, (c) VSWR of CPMA with inset feed, (d) real impedance of CPMA with inset feed

the impedance of the CPMA with inset is shown in Fig.3 (d) where the real impedance of the antenna is 42.25 Ω and 62.03 Ω for f_{r1} = 3.5 GHz and f_{r2} = 6 GHz, this shows that the antenna already has good compatibility with the impedance of the connector, which is 50 Ω.

3.3 Design and Simulation Process of CPMA with Inset and Slot

In this paper, slot loading is proposed to control and optimize both resonant frequencies and S_{11} of the CPMA. Fig. 4(a) shows that the slot is placed in the center of the CPMA with the length and width of the slot represented by L_s and W_s. The effect of adding a slot is that the permittivity of the antenna changes, this causes the resonant frequency and S_{11} of the antenna to change significantly. The dimensions of L_s are obtained from iterations with EM simulation while the dimensions of W_s are fixed, which is 1 mm.

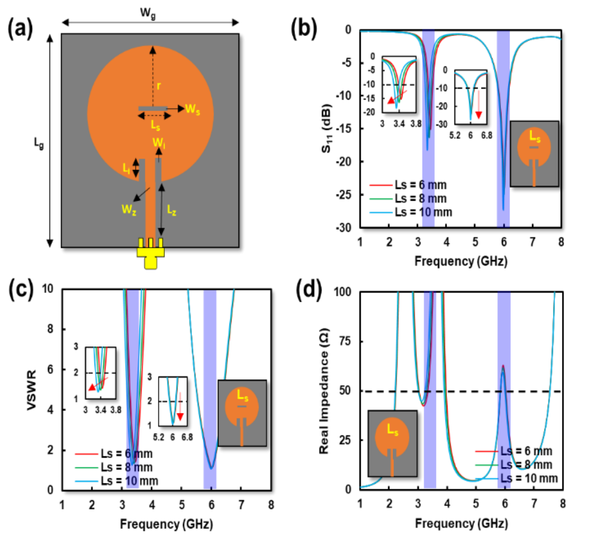

Fig. 4 – (a) Dimension of CPMA with inset feed and slot, (b) S_{11} of CPMA with inset feed and slot, (c) VSWR of CPMA with inset feed and slot, (d) real impedance of CPMA with inset feed and slot

Fig. 4(b) shows the arrangement of L_s affecting the resonant frequency and S_{11} for f_{r1}. Furthermore, for f_{r2} a significant effect only appears at S_{11} while for the resonant frequency it is fixed. The same findings are also obtained for the VSWR and the impedance of the proposed antenna. The best performance is obtained when L_i = 6 mm and W_i = 1 mm where S_{11} is – 16.42 dB and – 24.92 dB for both resonant frequencies while the VSWR of the proposed antenna is 1.45 and 1.25 as shown in Fig. 4(c), respectively. The impedance of the proposed antenna is shown in Figure 4(d) where for f_{r1} and f_{r2} are 62.93 Ω and 58.80 Ω, respectively. This shows that the addition of slots has succeeded in increasing the performance of the proposed antenna.

3.4 Design and Simulation Process of MIMO Dual-Band CPMA

The structure of the MIMO antenna consists of two or more patch antennas that are directly connected to the input port and separated by a certain distance. In this paper, a CPMA with two ports is proposed as a MIMO antenna as shown in Fig. 5.

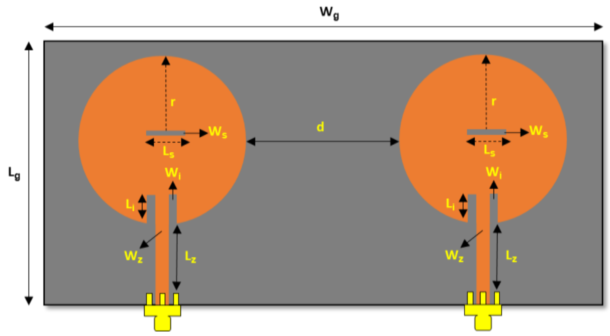

Fig. 5 – Proposed MIMO dual-band CPMA

Fig. 5 shows that each antenna is connected to port 1 and port 2 and separated by a distance (*d*). One of the problems with MIMO antennas is high mutual coupling, this is because the two antennas operate simultaneously at the same frequency and are close to each other. Thus, mutual coupling can be reduced by controlling the distance of the two antennas.

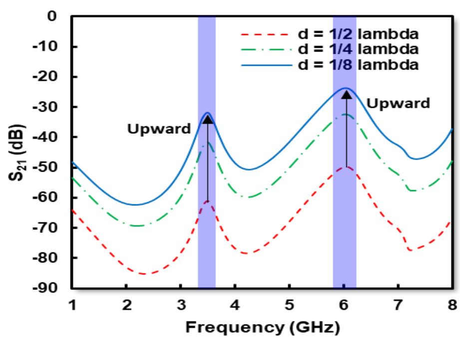

Fig. 6 – the simulation results from S_{21} from the distance iteration (*d*) where the proposed distance is in the range of $1/2\lambda$ – $1/8\lambda$

Fig. 6 shows the simulation results from S_{21} from the distance iteration (*d*) where the proposed distance is in the range of $1/2\lambda$ – $1/8\lambda$. The simulation results show that the distance between the antennas greatly affects the S_{21} of the MIMO antenna where low mutual coupling with S_{21} of – 61.10 dB and – 50.06 dB for f_{r1} and f_{r2} are obtained when $d = ½\lambda$.

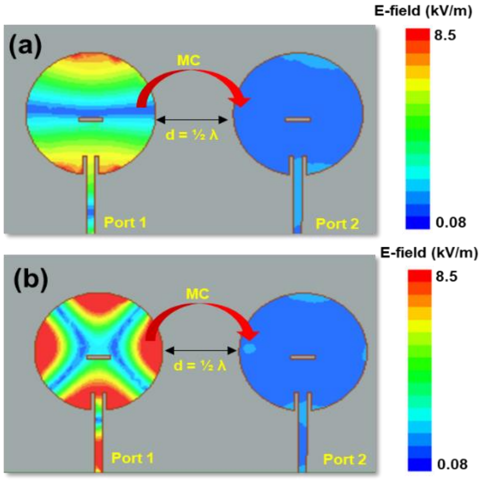

Fig. 7 – **E**-field concentration of proposed MIMO CPMA; (a) at f_{r1} = 3.5 GHz, (b) at f_{r2} = 6 GHz

Furthermore, Fig. 7 (a) and Fig. 7 (b) shows that the CPMA dual-band MIMO does not affect each other when operating simultaneously, this is indicated by the **E**-field concentration of the antenna on port 1 does not affect the antenna on port 2 for both resonant frequencies, respectively.

The radiation pattern of the proposed antenna is shown in Fig. 8 (a) and Fig.8 (b) where the maximum gain obtained is 7.8 dB and 7.1 dB for f_{r1} = 3.5 GHz and f_{r2} = 6 GHz.

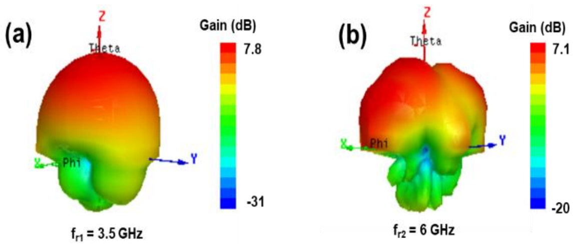

Fig. 8 – Radiation pattern of proposed antenna; (a) at f_{r1} = 3.5 GHz, (b) at f_{r2} = 6 GHz

As a fair comparison, Table 1 shows a comparison between the proposed antenna and the existing antenna.

Table 1 – Comparison with existing antenna.

Ref	Method	f_r (GHz)	Parameter			Multi-band Performance	MIMO capabilities for 5G
			S_{11} (dB)	S_{21} (dB)	Gain (dB)		
[14]	CSRR	4.2 5.5 9.7 13.9	≤ – 10	NA	8.27	Yes	No
[15]	CPW	2.7 3.6 5.6	≤ – 10	NA	5.1	Yes	No
[16]	MIMO Array	1.7 3.5	≤ – 10	≤ – 20	16	Yes	No
T.W	CPMA with inset feed and slot	3.5 6	≤ – 10	≤ – 20	7.8 7.2	Yes	Yes

T.W = this work

4. CONLUSION

In this paper, CPMA dual-band MIMO for 5G communication system has been successfully designed and simulated. The proposed antenna has dual-band characteristics operating at f_{r1} = 3.5 GHz and f_{r2} = 6 GHz. The performance of the antenna is optimized using inset feeds and slots while for mutual coupling reduction it is obtained by controlling the distance between patch antennas (d). From the simulation results, it is obtained that S_{11} is – 13.23 dB and – 22.35 dB with a gain of 7.1 dB and 7.2 dB for the two resonant frequencies, respectively. In addition, the proposed antenna also has low mutual coupling (S_{21}) ≤ – 20 dB where for f_{r1} = 3.5 GHz is – 50.12 dB and f_{r2} = 6 GHz is – 60.25 dB. This research is very useful and can be recommended as a receiving antenna for 5G communication systems.

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Двохдіапазонна MIMO кругла патч мікросмугова антена (CPMA) з низьким взаємним зчепленням для системи зв'язку 5G

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У даній статті запропонована кругова мікросмугова антена MIMO (CPMA), яка працює на резонансних частотах 3,5 ГГц і 6 ГГц для систем зв'язку 5G. Пропонована антена розроблена з використанням підкладки RO-5880 з діелектричною проникністю (εr) 2,2, товщиною (h) 1,58 мм і tan втрат (tan δ) 0,0009. Двохсмугова характеристика досягається шляхом розміщення щілини в центрі CPMA, тоді як вставний фідер використовується для контроля коефіцієнта відбиття. Крім того, зменшення взаємного зчеплення досягається шляхом керування відстанню між антенами, якщо вони налаштовані в MIMO. Виходячи з результатів моделювання, запропонована антена забезпечує відмінні характеристики з коефіцієнтом відбиття ≤ – 10 дБ і взаємним зв'язком (MC) ≤ – 20 дБ на резонансних частотах 3,5 ГГц і 6 ГГц.

Ключові слова: Дводіапазонний, Круглий патч, Мікросмугова антена, MIMO, 5G.