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Triple Band Notched Microstrip Antenna Using Planar Series 2×2 Element Array for 5G Communication System

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This research proposes the design of a wideband microstrip antenna with triple notch bands for the fifth generation (5G) communication system. The antenna is designed using FR-4 substrate with ε_r of 4.3, tanδ of 0.0265 and a thickness of 1.6 mm. Triple notch bands are generated using a 2×2 element array configuration that connects each patch antenna in series and is arranged horizontally. From the simulation results, a triple band notched antenna is obtained with a resonant frequency of 3.15, 3.32 and 3.72 GHz. The fractional bandwidth (FBW) of the proposed antenna is 770 MHz or 22 % and the gain is 9.24 dB with an operating frequency of 3.5 GHz. The proposed antenna succeeded in increasing the bandwidth and gain up to 285 % and 55 %, respectively, compared to a single element antenna. The studied antenna design can be recommended as it is also very useful as a receiving antenna for the 5G communication system.

Keywords: Microstrip antenna, Planar series array, Bandwidth, Triple band notched antenna.

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1. INTRODUCTION

The fifth generation (5G) communication system has been developed and has the advantages such as low latency and very high data transfer rates [1]. The data transfer speed and latency offered by the 5G communication system are up to 10 Gbps (gigabits per second) and 0.5 ms (milliseconds) and available at a frequency of 3.5 GHz [2]. To support the communication process between the customer and the provider, a transceiver device is needed that is useful for sending and receiving information signals. One of the recommended antennas for 5G communication systems is a microstrip antenna because it has the advantage of low profile, ease of manufacture and compact dimensions [3-5]. Several previous studies have described the application of microstrip antennas for 5G communication systems [6-8]. However, one of the disadvantages of microstrip antennas is narrow bandwidth, low gain and directivity. Several studies have been proposed to increase bandwidth, among others, by using coplanar waveguide (CPW) [9-11], proximity coupling [12], slot [13] and parasitic [14]. Furthermore, to increase the gain of microstrip antennas, several techniques have been described in previous studies, including array [15] and subarray [16]. The previous research proposed a microstrip antenna design with a 2×2 element array technique with the addition of stubs to optimize bandwidth [17], while another study [12] described an ultra-wideband antenna with a step line and a U-slot. However, the two studies only produced one notch of the operating frequency. This study proposes the design of a wideband microstrip antenna with a 2×2 element array configuration and arranged in a planar series for the 5G communication system. The main contribution of this research is to produce an antenna that has a wide bandwidth, high gain and a triple notch band of resonant frequency, so that it can be used as a receiving antenna in the 5G communication system. From the simulation results, the bandwidth and gain of the proposed antenna increase up to 285 % and 55 %, respectively. The structure of this paper consists of the introduction, antenna design, simulation results and analysis, and the last section is the conclusion.

2. ANTENNA DESIGN

The structure and development stages of the proposed antenna are shown in Fig. 1.

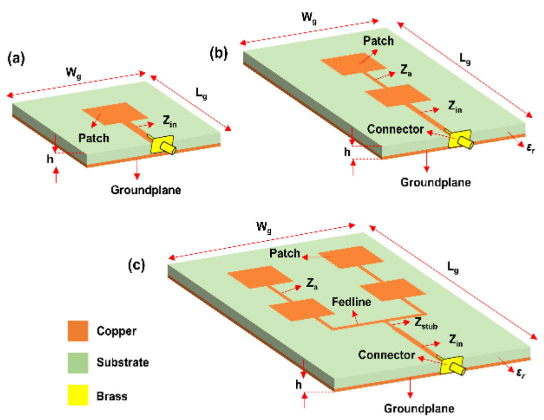

Fig. 1 – Design of the proposed antenna: (a) single element, (b) series array with 2×1 element, (c) planar series array with 2×2 element

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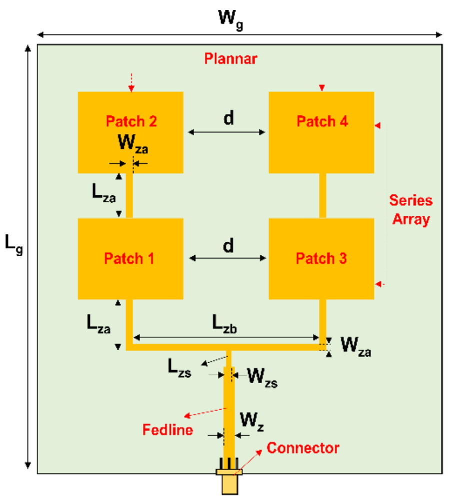

Fig. 2 – Dimension of a planar series array with 2×2 elements

The antenna is designed using FR-4 substrate with ε_r of 4.3, tanδ of 0.0265 and thickness (h) of 1.6 mm. The initial stage starts with designing a single element antenna and then develops it using a series array with 2×1 elements. To produce triple notch and high gain, a planar array with 2×2 elements is proposed in this paper as a solution. The design of the microstrip antenna consists of a patch as a radiating element, a ground plane as a reflector, a feed line as an input, and matching impedance between the antenna and the connector. The impedance of the connector used is 50 Ohm, while the feed line used is a microstrip line. The structure of the proposed antenna is shown in Fig. 2. The dimensions of the microstrip antenna are obtained using the following equations [18]:

$$W = \frac{C}{2f\sqrt{\frac{\varepsilon r+1}{2}}}, \quad (1)$$

$$L = L_{eff} - 2\Delta L, \quad (2)$$

$$\varepsilon_{r\,eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}}, \quad (3)$$

$$\Delta L = 0.412h\frac{\left(\varepsilon_{r\,eff}+0.3\right)\left(\frac{W}{h}+0.264\right)}{\left(\varepsilon_{r\,eff}-0.258\right)\left(\frac{W}{h}+0.8\right)}, \quad (4)$$

$$W_Z = \frac{2h}{\pi}\left\{B-1-\ln\left(2B-1\right)+\frac{\varepsilon_r-1}{2\varepsilon_r}\left[\ln\left(B-1\right)+0.39-\frac{0.61}{\varepsilon_r}\right]\right\}. \quad (5)$$

where $B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_{eff}}}$.

The geometry and dimensions of a series planar antenna with 2×2 elements are shown in Fig. 2, Table 1.

The radiating elements of the antenna array are separated by a distance denoted by d, this is aimed at increasing the antenna gain. Furthermore, the width of the feed line of the proposed antenna is adjusted to the impedances used Z_a = 100 Ohm, Z_{in} = 50 Ohm and Z_{stub} = 70.7 Ohm. The overall dimensions of the proposed antenna are shown in Table 1.

The application of a stub is aimed at reducing the reflection coefficient of the antenna. Moreover, the distance between elements denoted d and stub impedance are determined using the following equations:

$$d = \frac{1}{4}, \quad (6)$$

$$Z_{stub} = \sqrt{Z_{in}\cdot Z_a}. \quad (7)$$

Table 1 – Dimensions of the proposed antenna

Parameter	Dimension (mm)
W_g	90
L_g	120
W	26
L	20
W_z	3
L_z	41
W_{za}	2.1
L_{za}	12
W_{zs}	1
L_{zs}	5

The dimensions of the feed line with impedances of 50, 70.7 and 100 Ohms are denoted by the parameters W_z, W_{zs} and W_{za}, respectively. Furthermore, the dimensions of the substrate are denoted by the parameters W and L, while W_g and L_g denote the dimensions of the radiating element, and the distance between the elements is denoted by d.

3. RESULTS AND DISCUSSION

3.1 Simulation Results

The simulation process is carried out using EM simulation software by observing the reflection coefficient, VSWR, impedance and gain of the three proposed antennas. The simulation results of a single element antenna are shown in Fig. 3.

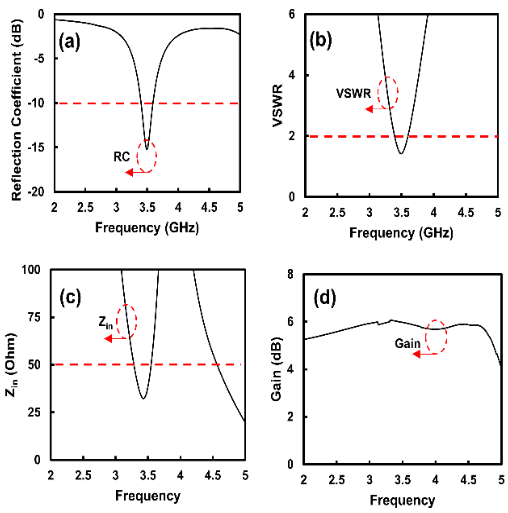

Fig. 3 – Simulation results of the single element antenna: (a) reflection coefficient, (b) VSWR, (c) Z_{in}, (d) gain

Fig. 3 shows that the single element antenna operates at a resonant frequency of 3.5 GHz with a reflection coefficient of – 15.21 dB, VSWR of 1.42, impedance of 38.61 Ohms and gain of 5.97 dB. The bandwidth of the single element antenna is 200 MHz with a frequency range of 3.4-3.6 GHz. Furthermore, the simulation results of a series array antenna with 2×1 elements are shown in Fig. 4.

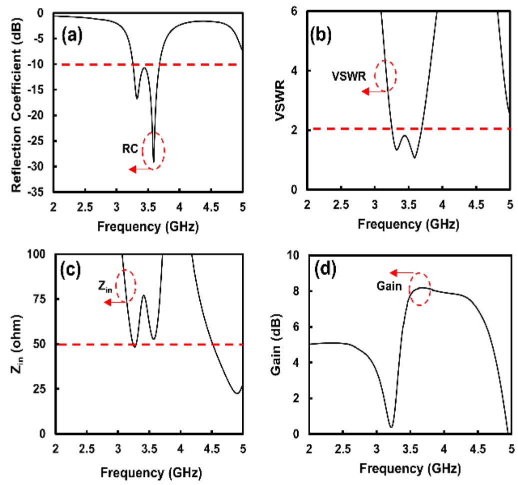

Fig. 4 – Simulation results of the series array antenna with 2×1 elements: (a) reflection coefficient, (b) VSWR, (c) Z_{in}, (d) gain

Fig. 4 shows that the series array antenna with 2×1 elements produces a wider bandwidth than the single element antenna, which is 420 MHz from the frequency range of 3.26-3.68 GHz. Furthermore, the series array antenna also produces two notch bands which have the best reflection coefficients of – 29.05 dB at a resonant frequency of 3.59 GHz and – 16.69 dB at a frequency of 3.32 GHz. The gain of the proposed antenna is also increased to 7.76 dB at a resonant frequency of 3.5 GHz while the impedance of the two notch bands is close to 50 Ohms. Furthermore, the simulation results of the reflection coefficient, VSWR, impedance and gain of a series planar array antenna with 2×2 elements are shown in Fig. 5.

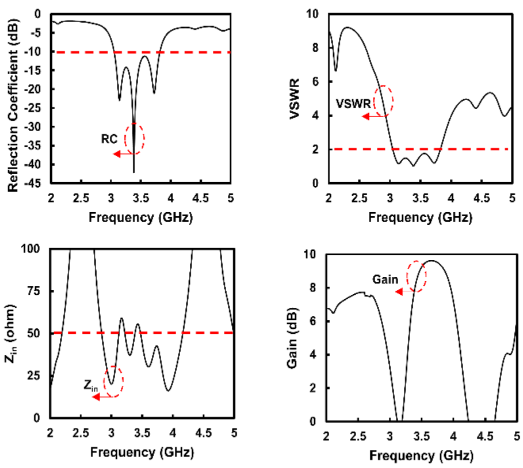

Fig. 5 – Simulation results of the series planar array antenna with 2×2 elements: (a) reflection coefficient, (b) VSWR, (c) Z_{in}, (d) gain

Fig. 5 shows that the series planar array antenna with 2×2 elements produces a wide bandwidth of 770 MHz with a resonant frequency range of 3.05-3.82 GHz. Furthermore, the proposed antenna produces three different notch bands at the resonant frequencies of 3.14, 3.38 and 3.72 GHz with the reflection coefficients of – 22.69, – 42.08 and – 21.46 dB, respectively. The gain of the planar array antenna is increased up to 9.24 dB and the impedance of the three notch bands is in the range of 50 Ohms.

3.2 Analysis of Simulation Results

Simulation results of the three antenna models were analyzed to observe the impact and changes in antenna characteristics before and after optimization with a series array and a series planar array. The parameters to be compared are the resonant frequency, bandwidth and gain of the proposed antenna. A comparison of the reflection coefficients of the three proposed antenna models is shown in Fig. 6.

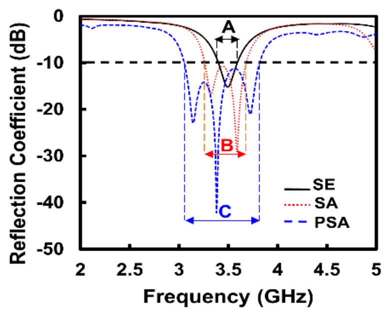

Fig. 6 – Comparison of reflection coefficient simulation results for three models of the proposed antenna

Fig. 6 shows that the antenna bandwidth is significantly increased with the addition of a series array and a series planar array. The antenna design with a series array has succeeded in increasing the bandwidth performance up to 110 %, while with a series planar array – up to 285 % compared to single element antennas, as indicated by A, B and C. Moreover, the number of notch bands of the proposed antenna also increases. The number of notch bands on a series array antenna is two at 3.2 and 3.59 GHz, while a series planar array gives three notch bands at 3.14, 3.38 and 3.72 GHz. Fig. 7 shows a comparison of the gains for the three proposed antennas.

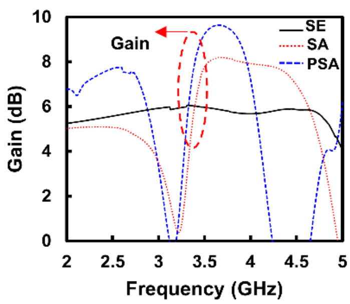

Fig. 7 – Comparison of gain simulation results

Fig. 7 shows that the gain of the proposed antenna is also significantly increased. The antenna gain increased up to 30 % and 54.7 % after optimization with a series array and a series planar array, respectively. The radiation patterns of the three proposed antenna models are shown in Fig. 8.

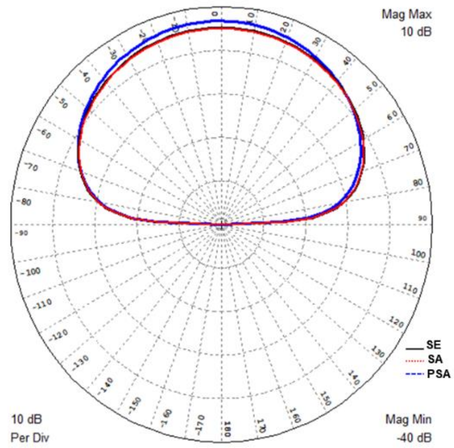

Fig. 8 – Comparison of radiation pattern simulation results

4. CONCLUSIONS

A wideband microstrip antenna with three notch bands has been described and studied in this paper. The bandwidth and gain of a single element antenna were successfully increased by using an array with 2×1 elements and a planar series array with 2×2 elements. The gain and bandwidth of the proposed antenna were significantly increased up to 54.7 % and 285 % when optimized with a planar series array. Furthermore, the three notch bands of the proposed antenna were successfully obtained with a planar array configuration at 3.14, 3.38 and 3.72 GHz. This proposed antenna can be recommended as a receiving antenna for the 5G communication system.

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Мікросмужкова антена з трьома режекторними смугами з використанням планарного масиву послідовних елементів 2×2 для системи зв'язку 5G

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У дослідженні пропонується конструкція широкосмугової мікросмужкової антени з трьома режекторними смугами для системи зв'язку п'ятого покоління (5G). Антена розроблена з використанням підкладки FR-4 з $\varepsilon_r = 4{,}3$, $\tan\delta = 0{,}0265$ і товщиною 1,6 мм. Потрійні режекторні смуги генеруються за допомогою конфігурації масиву з 2×2 елементів, в якій патч-антени з'єднані послідовно і розташовані горизонтально. За результатами моделювання отримано антену з трьома режекторними смугами з резонансною частотою 3,15, 3,32 та 3,72 ГГц відповідно. Відносна ширина смуги пропускання (FBW) пропонованої антени становить 770 МГц або 22 %, а коефіцієнт підсилення складає 9,24 дБ при робочій частоті 3,5 ГГц. Запропонована антена дозволила збільшити смугу пропускання та отримати коефіцієнт підсилення до 285 % та 55 % відповідно, у порівнянні з одноелементною антеною. Вивчена конструкція антени може бути рекомендована, оскільки вона є дуже корисною як приймальна антена для системи зв'язку 5G.

Ключові слова: Мікросмужкова антена, Планарний послідовний масив, Смуга пропускання, Антена з трьома режекторними смугами.