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A dual-band multiple-input multiple-output microstrip antenna with metamaterial structure for LTE and WLAN applications

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A R T I C L E I N F O

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A B S T R A C T

A method to enhance the gain of microstrip dual-band multiple-input multiple-output (MIMO) antenna using partially reflective surface (PRS) layer is introduced and investigated in this paper. The proposed antenna consists of two FR4 substrates. The lower substrate has two radiating patches with parasitic elements that are supplied independently and create the MIMO property of the antenna. The upper substrate which is known as superstrate is arrays of PRS unit cells. The PRS layer printed on either side of a dielectric substrate and causes the antenna gain to increase in both frequency bands. The proposed antenna is appropriate for LTE (2.4–3.1 GHz) and WLAN (5.1–5.8 GHz) applications. The measured values of S_{11} and S_{22} parameters of the antenna are less than −10 dB and its FBR and gain are 12.5 dB and 5dBi, respectively. The average half power beam-width (HPBW) is roughly 108°.

1. Introduction

Nowadays, some important features in wireless communications especially in antennas have attracted the attention of many researchers. These features include having high data transfer rate, overcoming multipath fading, having high gain, and having a wide radiation pattern which enables the antenna to cover a wider area. Therefore, in the design process of antennas tendency towards using approaches such as PRS or metamaterial structures which improve antenna bandwidth [1–4] and gain [5–8] has increased. Moreover, there has been an increase in using MIMO technology [9–15] due to capabilities such as high data transfer.

There are different methods for obtaining high gain such as using negative permeability with metamaterial unit cells [5], Fabry-Perot resonator microstrip patch antenna based on metamaterial structure [6] and zero-index metamaterial [7]. Authors in [8] proposed an array antenna with superstrate layer as metamaterial structure for enhancing the gain and bandwidth. This structure has been achieved by split ring resonators (SRR) and wire strips. But these antennas [6–8] don't cover lower frequency bands such as LTE applications. Also, in [16] multi parallel rings has been used as metamaterial layer to reduce the size of antenna. Despite suitable gain and efficiency of the antenna in [16], it cannot be used for MIMO applications. An antenna with a partial metamaterial loaded by rectangular split ring resonators was reported in [17]. This approach that provided the negative permeability characteristics metamaterial property has been used to obtain WiMAX and WLAN frequency bands. However, this antenna has approximately low gain without MIMO characteristics. A metamaterial slot antenna with multi-band characteristics for size reduction has been employed in [18]. Miniaturization in this antenna is accomplished by using metamaterial rectangular complementary split ring resonator (RCSRR) as the radiation patch. But it should be considered that this antenna doesn't have MIMO characteristics and also has low gain.

In this paper, a dual-band and multiple-input multiple-output antenna with a gain increased through PRS structure is presented for wireless communications. It consists of a lower layer with two radiating patches and slots which provide the MIMO property. Moreover, another substrate is placed on the upper layer at a certain distance to increase the gain. This antenna has a gain of ~4.5 dBi and HPBW of 105° within the frequency range of 2.4–3.1 GHz. Furthermore, it has a gain of ~5dBi and HPBW of 111° within the frequency range of 2.4–3.1 GHz. S_{11} and S_{22} less than −10 dB and an FBR higher than 12.5 dB are obtained for both frequency bands.

2. Design and configuration of the antenna

The presented antenna has two substrates with the same characteristics. The lower substrate comprises the main structure of the antenna with radiating patches and ground plate. The upper substrate which is placed at the height of H_d above the lower substrate and is

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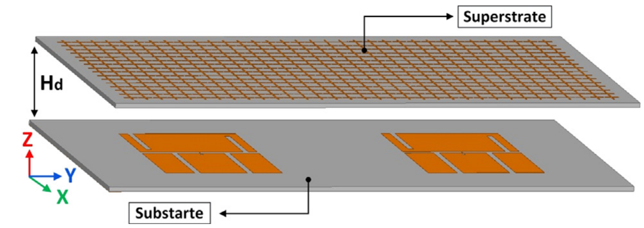

Fig. 1. Overall schematic view of the proposed antenna.

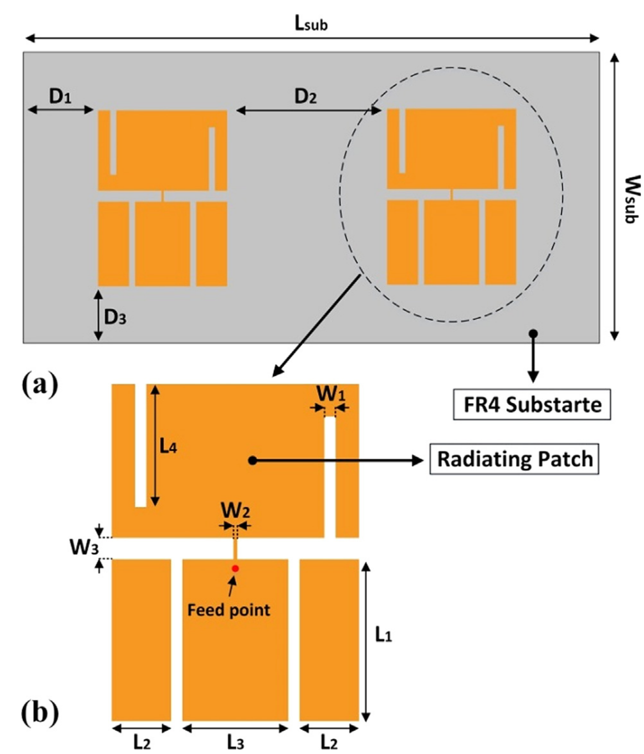

Fig. 2. Geometry of the lower layer of the proposed antenna.

Table 1
Overall dimensions of the presented antenna.

Parameters	Values	Parameters	Values
L_{sub}	180 mm	W-cell	5 mm
W_{sub}	90 mm	L-cell	5 mm
D_1	25 mm	L	4.7 mm
D_2	50 mm	L_1	26.47 mm
D_3	18.6 mm	L_2	10 mm
W	0.5 mm	L_3	16 mm
W_1	1.8 mm	L_4	20 mm
W_2	0.2 mm	H_d	27 mm
W_3	2 mm		

known as superstrate forms the structure of PRS. The overall schematic of the antenna is shown in Fig. 1. FR4 substrate with $\varepsilon_r = 4.4$, $\tan\delta = 0.01$ and dimensions of $180 \times 90 \times 1.6\,mm^3$ is used for both lower and upper layers.

As shown in Fig. 2, the antenna includes two similar square-shaped radiating patches in the lower substrate. The radiating patch has two slots with length of L_4 and width of W_1. These slots have the greatest impact at lower frequency band so that surface current distribution around these slots is maximized. Furthermore, two parasitic elements with dimensions of $L_1 \times L_2$ is used to control the frequency range especially at higher frequency band. The dimensions of antenna are presented in Table 1.

The upper substrate which is known as superstrate is placed at a distance of 27 mm from the lower substrate. This dielectric is composed of PRS unit cells array as mutual supplementary elements that embedded on both side of superstrate to obtain negative permeability. These unit cells are easy to implement with an FR4 substrate and also used as an insulator to reflect surface-waves based on the negative permeability characteristic. Fig. 3 shows the top and bottom sides of the superstrate. Each cell has dimensions of L-cell and W-cell. The top layer of superstrate consists of plus-shaped stubs with length and width of L × W. Also, the bottom layer of superstrate is composed of square-shaped cells with plus-shaped slots with the same length and width. Fig. 4 shows the manufactured antenna.

3. Results and parametric investigation

Fig. 5 shows the simulated and measured parameters of S_{11} and S_{22}. Considering these results, the proposed antenna resonates at the frequency ranges of 2.4–3.1 GHz and 5.1–5.8 GHz appropriate for LTE and WLAN applications. Comparing the obtained simulated and measured results it can be realized that the error in the first frequency band is much lower than the second frequency range which can be due to environmental factors and accuracy in the prototype antenna manufacture. The amount of isolation between ports 1 and 2 is also shown in Fig. 6. According to this figure, simulated and measured results for parameters S_{12} and S_{21} is less than −25 dB.

Fig. 7 shows the effect of superstrate on the antenna gain. As can be seen, with the existence of superstrate, the antenna gain in the frequency range of 2.4–3.1 GHz has increased by 2 dB and has reached the approximate value of ~5 dBi. This effect is also seen in the frequency range of 5.1–5.8 GHz but it is much smaller than the first frequency range. The gain in this range has increased by 1.5 dB and reached the approximate value of 6dBi. It can be concluded that with the existence of the superstrate, in addition to the increase in the gain in both frequency ranges, the antenna has a more stable gain compared to the case in which no superstrate is used. Moreover, the effect of the distance between substrate and superstrate on the input impedance of antenna is shown in Fig. 8. According to these results, the input impedance of the antenna increases with the distance variations of substrate and superstrate, especially in the second frequency range. However, these variations do not have a great impact in the first frequency range. Therefore, to reach a better impedance matching, the distance between the substrate and superstrate is considered to be 0.22λ (where λ is the wavelength in free space and at the frequency of 2.5 GHz).

Fig. 9 shows the FBR with and without superstrate of the presented antenna. This parameter is higher than 12.5 dB in both frequency ranges. Considering the values of this parameter, it can be concluded that the radiation pattern of the antenna can be fairly directional and the amount of radiation from the back of antenna ($\theta = -180^\circ$) is less than the amount of radiation from its top ($\theta = 0^\circ$). This can be investigated in the radiation pattern with and without superstrate that shown in Fig. 10. Also, comparison of simulated and measured radiation patterns are plotted at two frequencies of 2.5 GHz and 5.5 GHz and at $\varphi = 0^\circ$ in Fig. 11. Considering this figure and the FBR parameter it can be realized that the maximum intensity of radiation pattern is obtained at $\varphi = 0^\circ$ and $\theta = 0^\circ$. Furthermore, considering the wideness of radiation pattern, the half power beam-width is 105°at the frequency