A Camouflage Antenna Array Integrated with a Street Lamp for 5G Picocell Base Stations

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***Abstract*—This paper proposes a new design of a camouflage dual-polarized antenna for 5G picocell base stations. The antenna covers the frequency band from 3.25 GHz to 3.85 GHz with a good isolation between its ports (≥ 22 dB) and a low profile. The proposed antenna consists of two layers separated by an air gap (a radiating layer and a feeding layer). The radiating layer uses a transparent conducting film (Indium Tin Oxide) to form two patches (a radiating patch and a parasitic patch) printed on the opposite sides of a glass laminate. The radiating patch is meshed to improve the transparency of the antenna. The visual transparency of the radiating layer makes it possible to be integrated with the glass cover of the head of a street lamp while the feeding layer is embedded inside the head for camouflage. A 2 × 2 antenna array is formed to achieve a realized gain of 13.2 dBi and cover a solid angle of 33º × 33º making the proposed design a good candidate for the 5G picocell base stations.**

***Index Terms*— Dual-polarized, picocell, street lamp, camouflage.**

I. INTRODUCTION

As telecommunication vendors are about to introduce 5G mobile communication systems from 2019, base station and mobile antennas need to cover the new sub-6 GHz 5G frequency bands. In 2016, the European Commission (EC) announced its spectrum plan for 5G trials from 3.4 to 3.8 GHz. In 2017, the Chinese Ministry of Industry and Information Technology (MIIT) officially declared that 3.3-3.4 (indoor only), 3.4 -3.6 and 4.8-5 GHz bands were allocated for 5G services [1]. For base station antennas, diversity in polarization has been used to improve the signal-to-noise ratio (SNR) and system performance [2]. Nowadays, picocell (PC) base stations attract the attention of the research and the industry communities as they have the advantages of being small size, low power and low cost in comparison to the traditional cellular network [3].

For the 2G, 3G and 4G applications, Many successful designs have been introduced using planar cross dipoles [4] or 3D printed cross dipoles [5]. Furthermore, a quite few designs have been recently introduced for the sub-6 GHz 5G applications. In [6], stacked patch antenna was used to operate at a single frequency of 3.7 GHz. In [7], an antenna based on vector synthetic mechanism was introduced with a small size but its bandwidth (BW) is insufficient (3.3-3.6 GHz). In [8], the BW was improved at the expense of the antenna size. Later on, in [9], a 2×2 antenna subarray was used to provide a high gain covering the frequency band from 3.45 GHz to 3.55 GHz.

The concept of using a camouflage antenna in wireless communication has been adopted for both military [10] and civilian [11] applications. Furthermore, in [12], a transparent conductor printed on a glass substrate has been employed to form a transparent antenna.

In this paper, a novel transparent dual-polarized antenna for sub-6 GHz 5G PC base stations is proposed. The proposed antenna element covers the frequency band from 3.25 GHz to 3.85 GHz with a good isolation between its ports (better than 22 dB). It offers a high cross polarization discrimination ratio (XPD) and a stable radiation pattern within its frequency band in addition to its small size and low profile. The proposed antenna uses glass as a substrate for the radiating layer which makes it feasible to be integrated with the glass cover of the head of a street lamp for camouflage. The antenna element is amended to form a 2 × 2 antenna array with a realized gain of 13.2 dBi. A possible coverage scenario using the proposed PC base station is presented in Fig. 1.

The paper is organized as follows: Section II describes the proposed antenna element design; Section III presents its results and a comparison to the state-of-the-art reported designs; Section IV discusses a 2 × 2 square antenna array configuration and its results; Section V illustrates the integration of the antenna array with a street lamp and its effects on the antenna performance; and finally, conclusions are drawn in Section VI.

Fig. 1. The illustrative scenario of the 5G coverage area using the proposed PC base station.

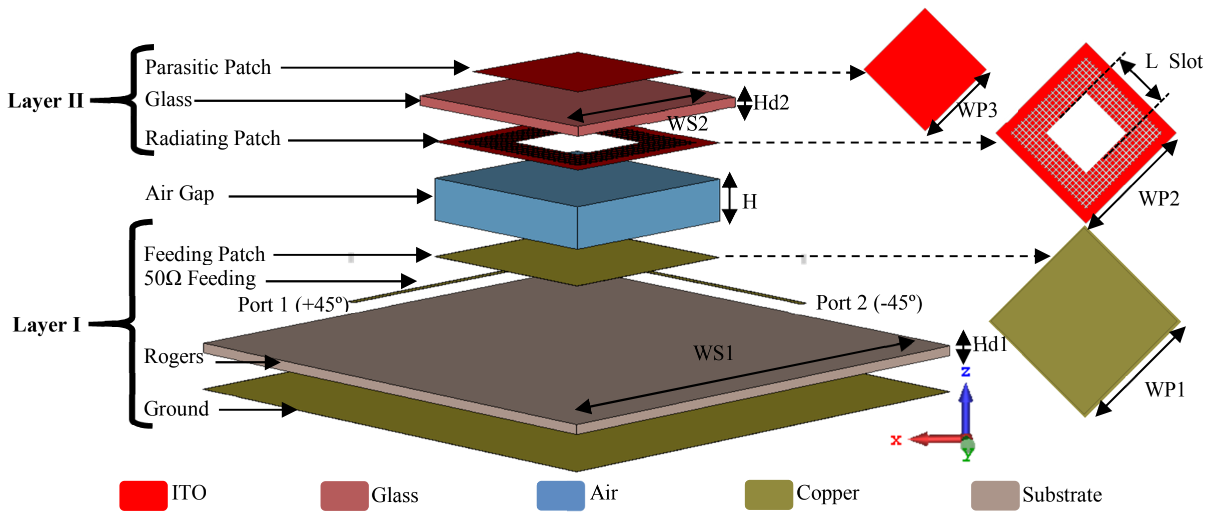

Fig. 2. The exploded geometry of the proposed antenna element.

II. Antenna Element Design

In this section, a novel dual-polarized antenna element covering the band from 3.25 GHz to 3.85 GHz is illustrated. Fig. 2 shows the exploded geometry of the proposed design. The antenna consists of two layers separated by an air gap. Layer I (the feeding layer) is a Rogers RT5880 laminate with thickness Hd1 = 1.6 mm, relative permittivity ε_{r1} = 2.2 and tangential loss of 0.0009. A square copper feeding patch is printed on the top of Layer I with two orthogonal 50 Ω feed lines for dual-polarization which are excited by two feeding ports. A copper ground plane is printed on the bottom side of Layer I to provide unidirectional radiation. Layer II (the radiating layer) is a glass laminate with thickness Hd2 = 1.8 mm, relative permittivity ε_{r2} = 4.8 and tangential loss of 0.0054. A radiating square patch using a thin film of Indium Tin Oxide (ITO) is printed with the same dimensions as the feeding patch on the bottom side of Layer II. The thickness of the used ITO film is 185 nm and its conductivity is 9×10^5 S/m to achieve a transparency of 80% [13]. A square slot is cut in the middle of the radiating patch to improve the impedance matching and the transparency. The radiating patch is meshed in the form of a net to further improve the transparency without scarifying the antenna performance. A parasitic ITO patch is printed on the top side of the glass laminate to improve the impedance matching by adding a capacitive loading to the antenna input impedance. The two layers are separated by an air gap of a height of H. The two layers are oriented in the XY plane. The two layers, the three patches (feeding, radiating and parasitic patches) and the square slot are concentric. For ± 45° dual-polarization, the side lengths of the layers, patches, feed lines and slot form angles of ±45° with the X and Y axes respectively. The optimized dimensions (in mm) are determined as: WP1 = WP2 = 27, WP3 = 20, WS1 = 71, WS2 = 30, L_Slot = 12, and H = 7.

III. Antenna Element Results

The proposed antenna element has been designed and simulated using CST microwave studio. Fig. 3 illustrates the reflection coefficient, the transmission coefficient between the ports, the antenna realized gain and the antenna total efficiency. It is evident that the antenna covers a BW of 600 MHz (from 3.25 to 3.85 GHz) with a reflection coefficient less than -10 dB and isolation between the ports better than 22 dB. The antenna has a stable realized gain of 8 dBi and a total efficiency of 76 ± 3% within the desired frequency band.

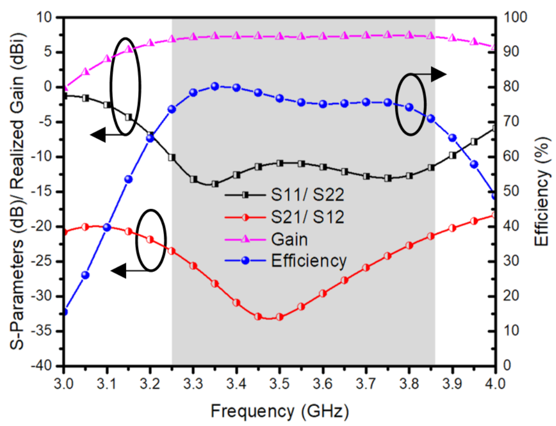

Fig. 3. Simulated reflection coefficient, isolation between the ports, realized gain and total efficiency.

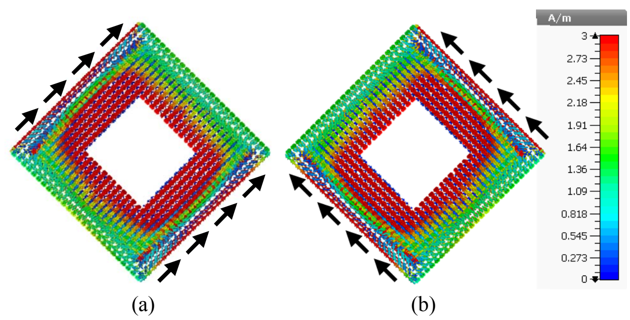

Fig. 4. The current distributions across the radiating patch at the central frequency feeding from (a) port 1 (b) port 2.

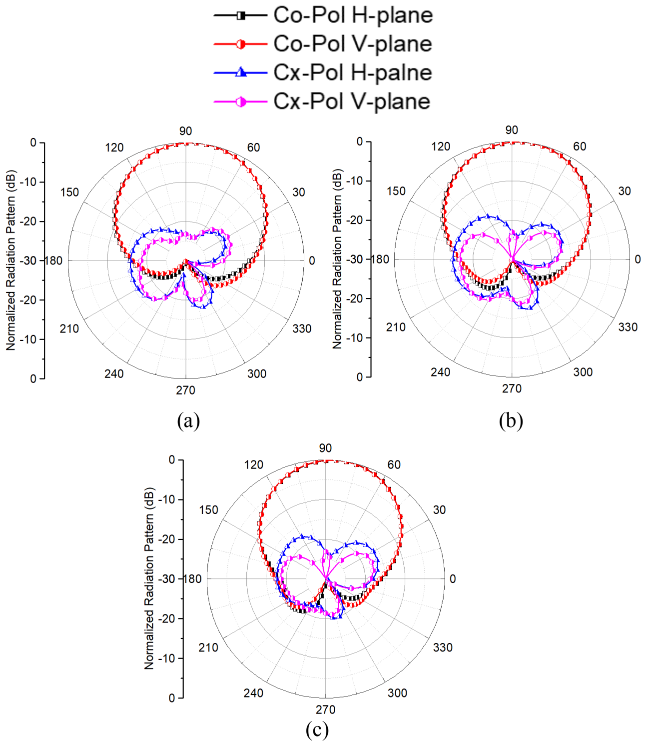

Fig. 5. Radiation patterns at (a) 3.25 GHz (b) 3.55 GHz (c) 3.85 GHz.

Fig. 4 shows the current distributions across the radiating patch at the central frequency (3.55 GHz) feeding from port 1 (+ 45°) and port 2 (- 45°). It is evident that the two current distributions are symmetrically inversed which indicates good isolation between the ports and high XPD between the co- and cross-polarized radiation patterns.

The simulated co-and cross-polarized radiation patterns at the start, central and stop frequencies in H-plane (XZ plane) and V-plane (YZ plane) are shown in Fig. 5. Because the structure is almost symmetrical around the X and Y axes, both the HPBWs in H-plane and V-plane are about 67.5 ± 2.5° across the frequency band. The XPD is better than 23 dB at boresight.

A comparison between the state-of-the-art sub-6 GHz 5G antennas reported in the literature and the proposed antenna is tabulated in Table I. It is apparent that the proposed antenna design has the widest BW, a small size, a stable gain with a good isolation between its ports and a high XPD.

TABLE I. COMPARISON OF REPORTED SUB-6 GHZ 5G BASE STATION ANTENNAS TO THE PROPOSED ANTENNA

Ref.	[6]	[7]	[9]	**Proposed**
Frequency (GHz)	3.65-3.81	3.3-3.6	3.45-3.55	**3.25-3.85**
Size (mm^3)	86×81×3	72×72×18.8	74×74×1.5	**71×71×10**
Isolation (dB)	31	28.8	15	**22**
Average gain (dBi)	10	8.2	8	**8**
Polarization	Dual	Dual	Single	**Dual**
XPD (dB)	23	24	NA	**23**

IV. A 2 × 2 ANTENNA ARRAY

To increase the antenna gain, a square 2 × 2 antenna array is formed as shown in Fig. 6. The spacing between any two adjacent elements is set to 65 mm (0.8λ_0 where λ_0 is the free space wavelength at the central frequency 3.55 GHz).

The reflection coefficient and the isolations between the ports (P1, P2… P8) for the antenna array are shown in Fig. 7. The results indicate a 10 dB return loss across the desired BW from 3.25 to 3.85 GHz and a worst-case isolation of 20 dB between any pair of ports.

The simulated 3D radiation pattern of the antenna array at the central frequency is shown in Fig. 8. The realized gain of the antenna array is 12.8 dBi and the HPBW is 33° in both V and H planes.

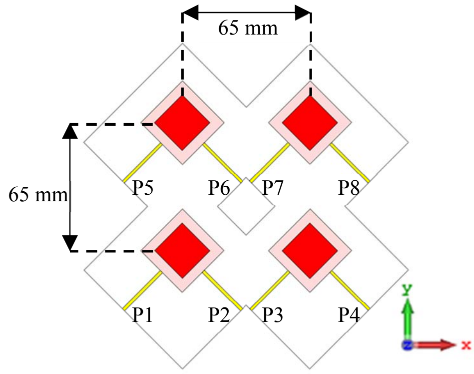

Fig. 6. The geometry of the proposed 2 × 2 antenna array.

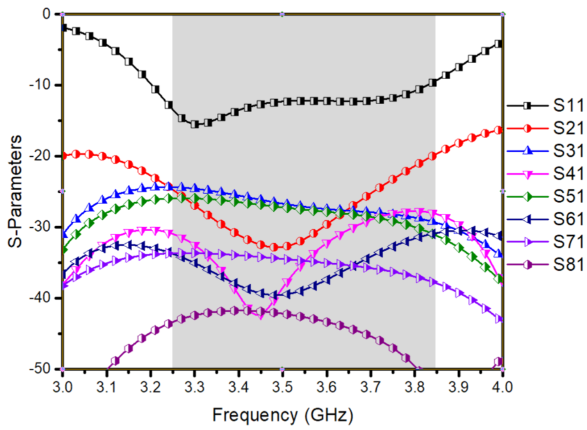

Fig. 7. Simulated S-parameters of the proposed antenna array.

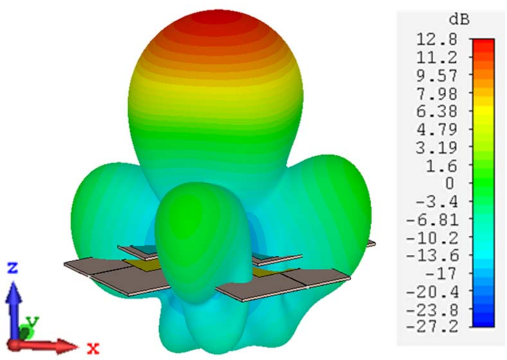

Fig. 8. The simulated 3D radiation pattern of the proposed antenna array.

V. Integrated Antenna Array with a Street Lamp

To achieve camouflage, the proposed antenna array presented in section IV is integrated with the head of a street lamp. The transparent radiating layer is integrated with the transparent glass cover of the head of the street lamp while the feeding layer is embedded inside the head as shown in Fig. 9. The two layers are separated by an air gap of a height H. To study the effect of the street lamp on the antenna performance, the antenna array was re-simulated after integration with the head of the street lamp using CST microwave studio and the simulated 3D radiation pattern is presented in Fig. 10. It is clear that the antenna realized gain has slightly increased to be 13.2 dBi due to the effect of the large metal reflector of the head of the street lamp

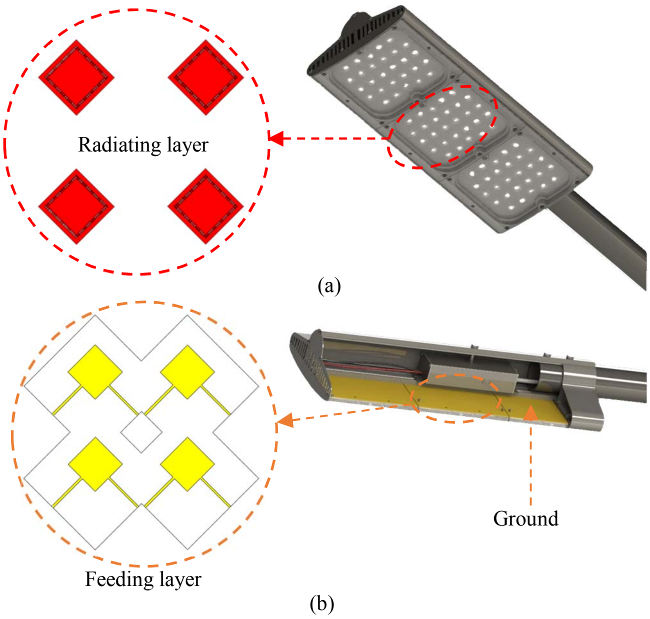

Fig. 9. Integration of the proposed antenna array with a street lamp (a) radiating layer (b) feeding layer

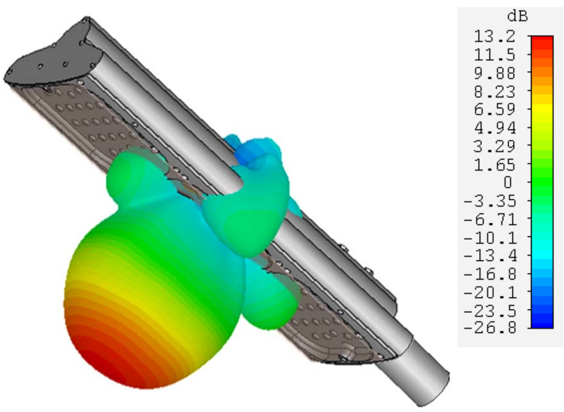

Fig. 10. The simulated 3D radiation pattern of the proposed antenna array integrated with a street lamp

VI. Conclusion

A new transparent dual-polarized antenna for PC base stations has been designed to serve the sub-6 GHz 5G applications. The antenna radiates through a transparent patch formed using a thin film of a transparent ITO conductor printed on a glass laminate achieving 80% of transparency. The proposed antenna covers the frequency band from 3.25 GHz to 3.85 GHz with a good isolation between its ports. It also has a stable radiation pattern within the desired frequency band with a small size and low profile. The proposed antenna has been amended to form a 2 × 2 antenna array to improve the antenna gain.

Being transparent, the antenna array has been feasible to be integrated to the head of a street lamp to achieve camouflage which makes the proposed design an ideal antenna candidate for camouflage sub-6 GHz 5G PC base stations. The design is to be made and tested. The results will be presented at the conference

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