Circularly polarised MIMO ground radiation antennas for wearable devices

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Two ground radiation antennas with polarisation diversity performance were proposed for MIMO WLAN applications in wearable devices. The antennas can simultaneously excite the vertical mode and horizontal mode of the ground plane and the phase difference between the two modes can be controlled by utilising an inductor-loaded metal strip in the ground plane, generating circular polarisation. A 3:1 VSWR bandwidth of 140 MHz with high isolation (above 17 dB) and a 3 dB axial ratio bandwidth of 100 MHz was obtained. The opposite rotations generated by the two antennas resulted in good diversity performance, which was verified by the measured envelope correlation coefficient.

Introduction: With the rapid development of wireless communication, high-speed data transmission and reception are required in wearable devices. Therefore, MIMO technology is essential to achieve diversity performance, which greatly increases the communication capacity [1, 2]. Furthermore, antennas with circular polarisation (CP) are also desired due to their advantages of reduced polarisation loss and less multipath interference compared with linear polarisation (LP). However, most previous studies on wearable devices focus on single-input single-output and LP antennas [3–5], which obviously cannot meet the increasing requirements. Therefore, CP MIMO antennas with polarisation diversity performance are necessary for wearable devices for next-generation communications [6].

In this letter, MIMO ground radiation antennas with CP performance are proposed in a small ground plane for WLAN applications. Ground radiation antennas are small loop-type antennas with lumped elements that can excite the ground plane as a radiator [7–10]. The antennas are symmetrically located in the top-right and top-left sides of the ground plane so that they can simultaneously excite both the vertical mode (along the x-axis) and the horizontal mode (along the y-axis) of the ground plane. An inductor-loaded metal strip is utilised at the bottom of the ground plane to tune the vertical mode of the ground plane inductive, generating a 90° phase difference from the horizontal mode. Right-hand CP (RHCP) and left-hand CP (LHCP) are generated in the $+z$-direction for the two antennas, respectively, and provide both high isolation and a low envelope correlation coefficient (ECC).

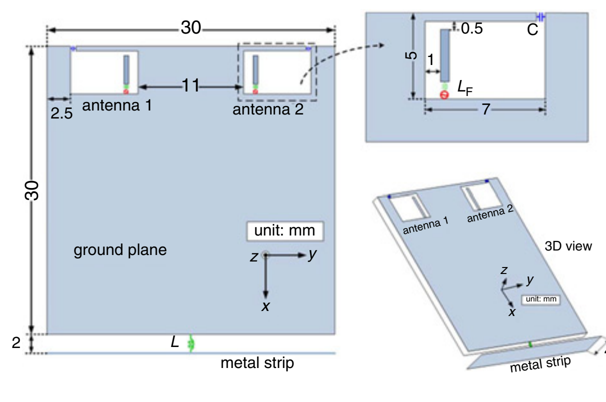

Fig. 1 *Configurations of proposed CP MIMO ground radiation antennas*

Antenna configuration: Fig. 1 shows the geometry of the proposed CP MIMO ground-radiation antennas in a 30×30 mm^2 ground plane etched on a 1 mm thick FR-4 substrate ($\varepsilon_r = 4.4$, tan $\delta = 0.02$). The antennas (antenna 1 and antenna 2) are located within small clearances of 5×7 mm^2 at the top-right and top-left sides of the ground plane, respectively. Each antenna is comprised of a feeding loop connected by a series inductor L_F (20 nH) and a radiation loop connected by a series capacitor C (0.27 pF), so that the impedance matching and resonance frequency can be easily controlled by tuning the values of L_F and C, respectively. The edge-to-edge distance between the two antennas is only 11 mm. The location of the antennas is such that they can simultaneously excite the vertical mode (along the x-axis) and the horizontal mode (along the y-axis) of the ground plane. Note that the widths of all the conducting traces in the proposed antenna are 0.5 mm.

To generate a phase difference between the two ground modes, an additional metal strip is connected to the ground plane through an inductor L (1 nH) at the centre of the bottom edge. The strip is placed 2 mm away from the ground plane and 4 mm wide in the z-axis so that it can be integrated into wearable devices. Therefore, the vertical mode resonance of the ground plane can be tuned by easily adjusting the values of L [8, 9], which provides a phase difference between the vertical and horizontal modes at the operating frequency.

Simulation results: The simulated S-parameters of the proposed antennas with and without the metal strip are shown in Fig. 2. As shown, the proposed antenna can achieve a 3:1 voltage standing wave ratio (VSWR) bandwidth of 140 MHz (from 2.38 to 2.52 GHz), fully covering the 2.4 GHz WLAN band. High isolation is obtained above 17 dB, which can be seen from the mutual coupling (S_{12}) curve in Fig. 2. In addition, the proposed antenna design can achieve a 6 dB higher isolation than that without the metal strip without significantly affecting the antenna performance (S_{11}/S_{22}).

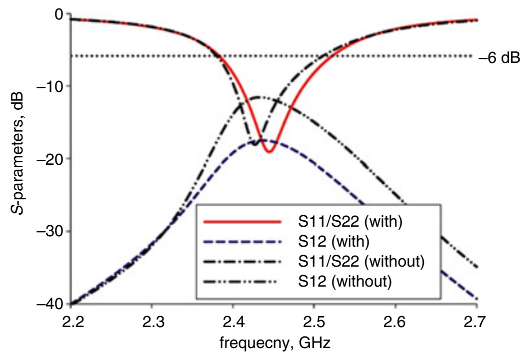

Fig. 2 *Simulated S-parameters of proposed antennas with and without metal strip*

The axial ratio (AR) is an important parameter for evaluating the CP performance. Therefore, the AR values in the $+z$ direction are calculated in Fig. 3. The 6 dB AR bandwidth is 240 MHz from 2.37 to 2.61 GHz (3 dB AR bandwidth of 100 MHz from 2.40 to 2.50 GHz). In comparison, the antenna design without the metal strip can only generate an LP with an AR value higher than 20 dB. This demonstrates the importance of the metal strip for CP generation. The simulated radiation patterns in the xz-plane at 2.45 GHz are presented in Fig. 4. For antenna 1, the RHCP and LHCP are generated in the $+z$-direction and $-z$-direction, respectively, as shown in Fig. 4*a*. In contrast, antenna 2 generates the opposite rotation as shown in Fig. 4*b*. This combination is favourable for diversity performance.

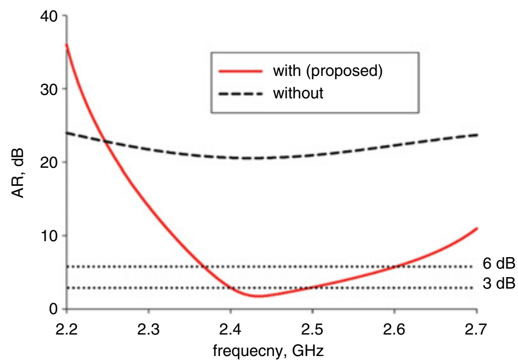

Fig. 3 *Simulated AR values in +z direction with and without metal strip*

Measurement results: The proposed antennas were fabricated, and the measured S-parameters are shown in Fig. 5. The 3:1 VSWR bandwidth ranges from 2.37 to 2.54 GHz and the isolation between antennas is above 20 dB, indicating that the measurement results agree well with the simulation. Furthermore, the total measured efficiencies of the proposed antennas are from −4 to −3.3 dB (see Fig. 5). In Fig. 6, the AR values in the $+z$-direction were measured and plotted over the operating frequency band, which ranges from 1.5 to 2.4 dB. This measurement sufficiently satisfied the required polarisation performance.

Finally, the ECC values were calculated and measured using 3D radiation patterns, and all the values were below 0.1, indicating the good diversity performance of the proposed antennas.

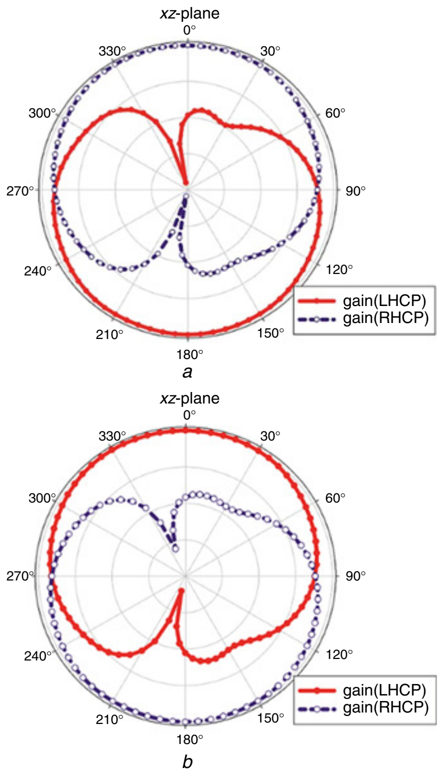

Fig. 4 *Simulated normalised radiation patterns in xz-plane of proposed antennas*

a Antenna 1
b Antenna 2

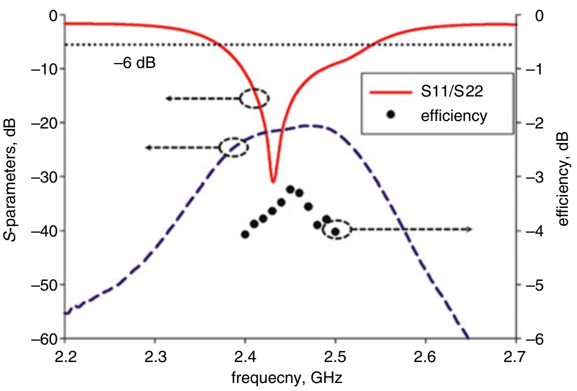

Fig. 5 *Measured S-parameters and total efficiencies of proposed antennas*

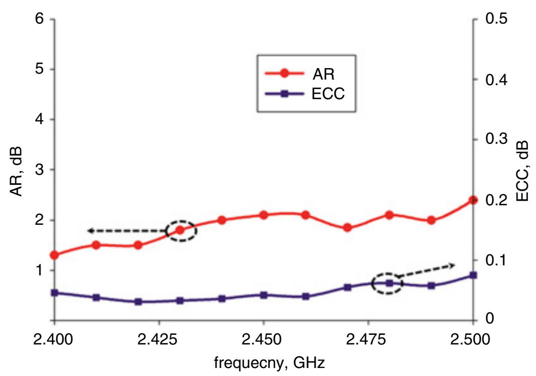

Fig. 6 *Measured AR and ECC values of proposed antennas*

Conclusion: In this letter, ground radiation antennas with CP performance have been proposed for MIMO WLAN applications in small wearable devices. Using a tunable metal strip, the proposed antennas can generate CP with opposite rotations, which provide high isolation (above 20 dB) and low ECC (below 0.1) based on the measurements. The antenna size, ground plane, and metal strip are compact and can be integrated into wearable devices. Therefore, the proposed antennas can provide both polarisation diversity performances for next-generation communications.

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One or more of the Figures in this Letter are available in colour online.

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