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Wireless Local-area-network Two-port Open-slot Antenna Array for Wireless Energy-harvesting Sensor Applications

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Recently, an energy-harvesting antenna array has been used for modern wireless sensor applications. In this paper, the design of a two-port open-slot antenna array operated at the wireless local-area-network (WLAN) 2.4/5.2/5.8 GHz for wireless energy-harvesting sensor applications is investigated. The overall size of the proposed antenna is only 60 × 70 mm^2 and printed on a flame retardant 4 (FR4) substrate with a thickness of 0.8 mm, a permittivity of 4.4, and a loss tangent of 0.0245 S/m. Furthermore, the antenna array has two ports and consists of two antenna arrays; the left side is designed for the WLAN 2.4 GHz band and the right side is designed for the WLAN 5.2/5.8 GHz bands. Both are printed on the front of the substrate, and the feeding network is printed on the back of the substrate. A metal reflector is added above the antenna to improve its radiation efficiency, gain, and directivity. The antenna of the proposed design can be operated at WLAN 2.4/5.2/5.8 GHz for wireless energy-harvesting sensor applications.

1. Introduction

With the continuous innovation of science and technology, wireless communication products are affecting our lives. Recently, the Internet of Things (IoT) has become a hot research topic; however, uninterrupted electricity is still a serious problem for these modern wireless products. Thus, for wireless sensors and their applications, an antenna array with the function of energy harvesting should be developed urgently. Zhu *et al.* developed a 4–5 GHz antenna for energy harvesting applications.(1) The 2.45 GHz antennas with simple structures and high gains for low-power energy harvesting were presented.(2,3) To ensure stability, the energy-harvesting systems were completed with the use of slot antennas.(4,5) Dual-band antennas were used for power harvesting or sensor network applications.(6–8) The authors used antenna arrays to complete the RF energy harvesting.(9–13) An antenna that could transfer electromagnetic wave energy to wireless sensor nodes was developed.(14) Thus, in this paper, a two-port open-slot antenna for wireless local-area-network (WLAN) 2.4/5.2/5.8 GHz energy-harvesting sensor applications was developed. The design procedures, S parameters, gains, and radiation patterns of the proposed antenna were investigated.

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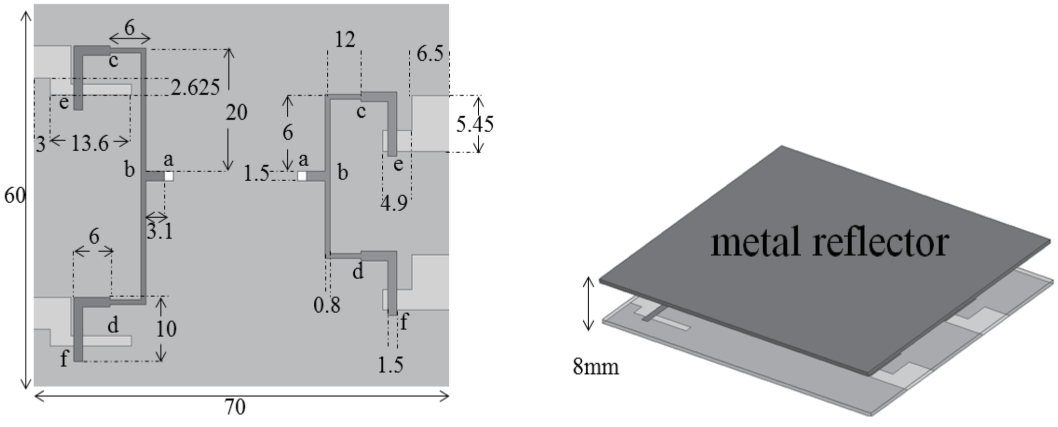
2. Experimental Procedure

A two-port open-slot antenna operated at WLAN 2.4/5.2/5.8 GHz for wireless energy-harvesting sensor applications was designed and fabricated on a flame retardant 4 (FR4) substrate with dimensions of 60 × 70 mm^2, thickness of 0.8 mm, relative dielectric constant (ε_r) of 4.4, and loss tangent (tan δ) of 0.024. To improve antenna gain and radiation efficiency, a metal reflector the same size as the substrate was placed on the proposed antenna of 8 mm height. Detailed structure parameters and three-dimensional (3-D) geometry are shown in Fig. 1. The design is composed of two array antennas; in addition, the left array antenna is operated at the WLAN 2.4 GHz band and the right array antenna is operated at the WLAN 5.2/5.8 GHz bands. Figure 2 shows the impedances for nodes a, c, d, e, f, g, and h. In this array antenna, the same impedance was designed for the left and right antennas, but because of the different operation bands (2.4 and 5.2/5.8 GHz) of these two antennas, their electric lengths were unequal. Thus, the width of the left ab section was designed as 1.5 mm with an impedance equal to 50 Ω. The width of the left cd section was designed as 0.8 mm with an impedance equal to 100 Ω and length equal to 3λ_g/4 (52 mm). Hence, the impedance of node b is equal to 50 Ω (two 100 Ω sections are parallel). On the other hand, the width of the right cd section was designed as 0.8



(a) (b)

Fig. 1. Geometry of proposed antenna. (a) Top and (b) 3-D views.

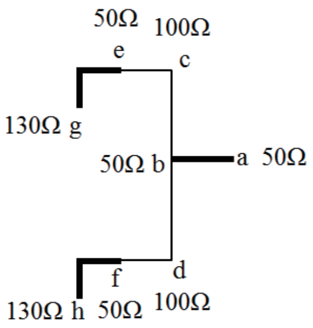


Fig. 2. Impedance of nodes.

mm with an impedance equal to 100 Ω and length equal to $5\lambda_g/4$ (37 mm). The impedance of node b is also equal to 50 Ω (two 100 Ω sections are parallel). The width of sections eg and fh was designed as 1.5 mm with an impedance equal to 81.5 Ω and length equal to $\lambda_g/4$ (16 mm).

3. Results and Discussion

Figure 3 shows the measured and simulated S parameters (S_{11}, S_{12}, and S_{22}) of the designed antenna. It can be seen that the measured S parameters are in good agreement with the simulated ones. In addition, the S_{11} curve includes the WLAN 2.4–2.484 GHz band, and the S_{22} curve includes the WLAN 5.15–5.35 GHz and WLAN 5.725–5.825 GHz bands. All of them are lower than −10 dB and the isolations (S_{12}) of these three bands are greater than −22 dB; this means that mutual effects of these two antennas are very low. Hence, the measured and simulated S parameters of the designed antenna are involved in the WLAN 2.4/5.2/5.8 GHz bands.

The simulated antenna gains and radiation efficiencies of the proposed design are presented in Fig. 4. For the 2.4–2.484 GHz bands, the antenna gains varied between 2.07 and 2.67 dBi, and the radiation efficiencies varied from 74 to 77%. For the 5.15–5.35 GHz bands, the antenna gains varied between 4.75 and 5.48 dBi, and the radiation efficiencies varied from 83 to 91%. Finally, for the 5.725–5.825 GHz bands, the antenna gains varied between 5.21 and 6.03 dBi, and the radiation efficiencies varied from 88 to 89%. As mentioned above, the proposed antenna reveals good and stable gains and efficiencies.

Figure 5 shows the simulated 3-D radiation patterns of the designed antennas with and without a metal reflector simulated at 2.45, 5.15, and 5.82 GHz, respectively. Comparing all the *X*–*Z* and *Y*–*Z* planes, we can observe that, owing to the metal reflector, all the radiation patterns of these bands become more focused along the −*Z*-direction (the red axis). This means that the proposed antenna has the advantage of good directivity.

To investigate the effect of the distance between the metal reflector and the antenna, the variations of gains for four different distances (4, 6, 8, and 10 mm) are shown in Fig. 6. It

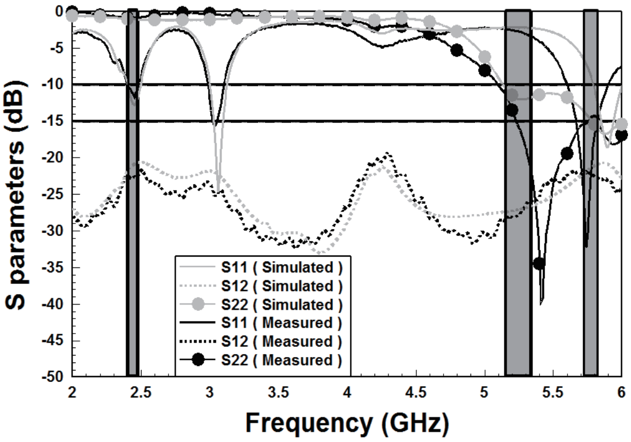
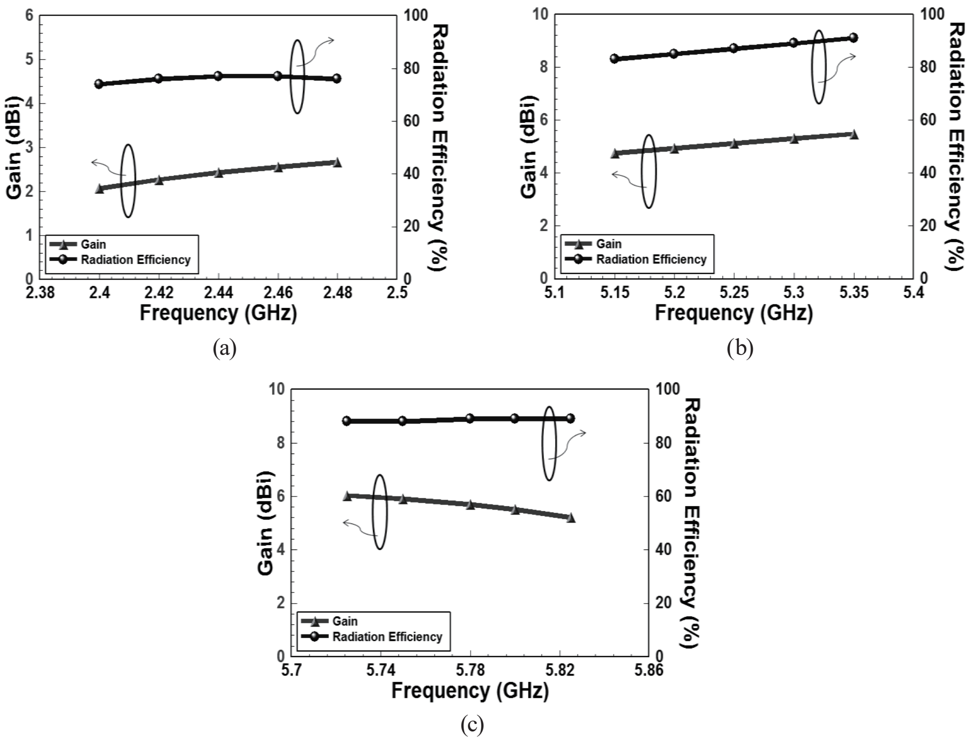


Fig. 3. Measured and simulated S parameters of proposed antenna.

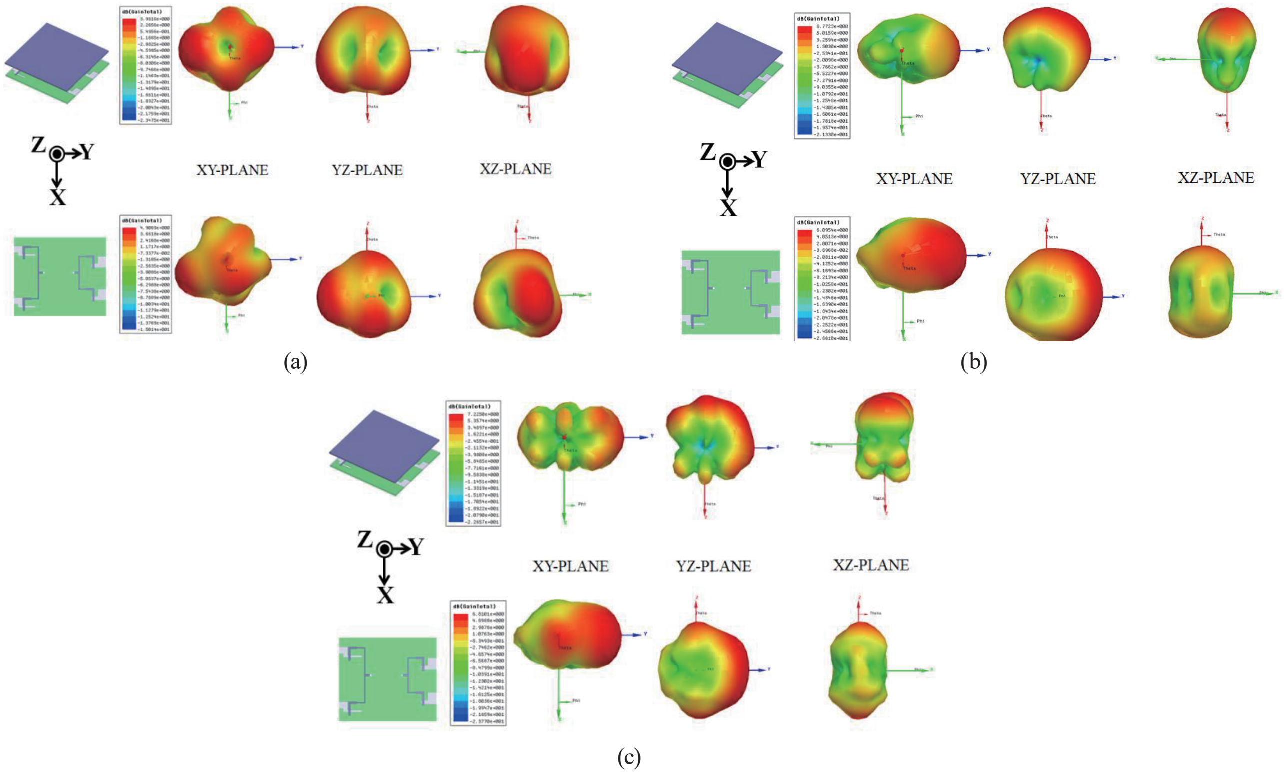


(a)

(b)

(c)

Fig. 4. Simulated antenna gains and radiation efficiencies. (a) 2.38–2.5, (b) 5.1–5.4, and (c) 5.7–5.86 GHz.

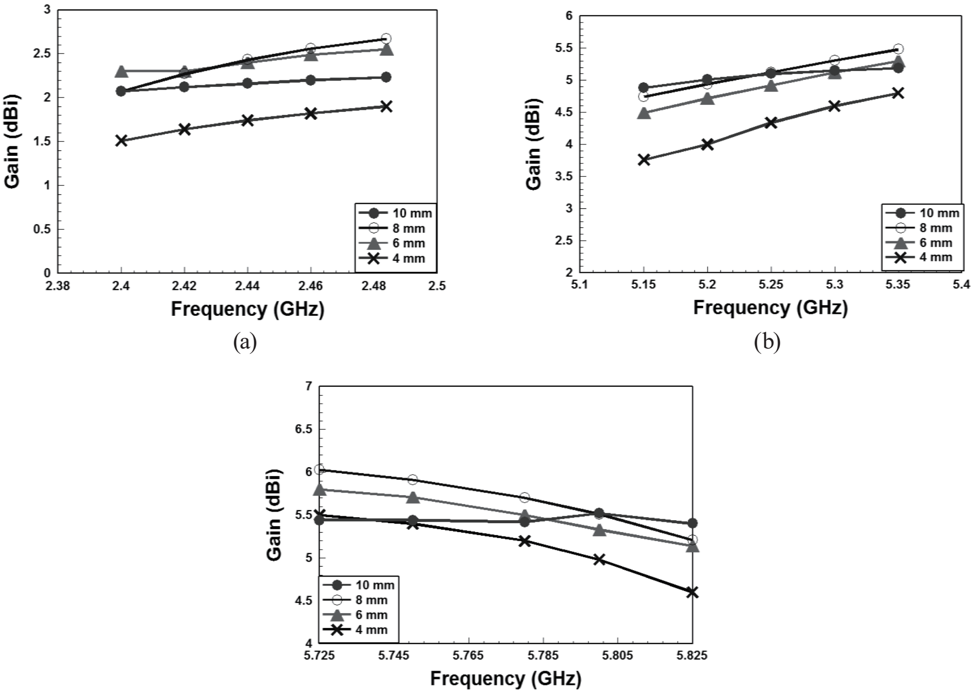


(a)

(b)

(c)

Fig. 5. (Color online) Simulated 3-D radiation patterns of the proposed antennas with and without a metal reflector. (a) 2.45, (b) 5.15, and (c) 5.82 GHz.



(a) (b)

(c)

Fig. 6. Simulated antenna gains for different distances between metal reflector and proposed antenna. (a) 2.38–2.5, (b) 5.1–5.4, and (c) 5.7–5.86 GHz.

can be found from the figure that, when the distance is 8 mm, the proposed antenna exhibits stablility and the best gains (2.1–2.6 dB for 2.4–2.485 GHz, 4.75–5.4 dB for 5.15–5.35 GHz, and 6.02–5.2 dB for 5.725–5.825 GHz). Hence, in this research, we choose 8 mm as the optimum distance between the metal reflector and the antenna.

4. Conclusions

A design of a two-port open-slot antenna array operated at WLAN 2.4/5.2/5.8 GHz for energy harvesting of wireless sensor applications is presented. Another metal reflector is added at a distance of 8 mm to improve the radiation directivity and gain. All the measured and simulated S_{11} and S_{22} values are lower than −10 dB, and the isolation (S_{12} value) is up to −22 dB. The operation bands of the proposed antenna can involve all the WLAN 2.4/5.2/5.8 GHz bands, indicating that they can be used as energy-harvesting antennas in the future.

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