Dual-band CPW-fed cross-slot monopole antenna for WLAN operation

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Abstract: A novel dual-band design of a coplanar waveguide (CPW)-fed monopole antenna with a cross slot is proposed. The antenna, comprising a planar patch element embedded with a cross slot, is capable of generating two separate resonant modes with good impedance matching conditions. Prototypes of the proposed antenna have been constructed and experimentally studied. The measured results show both good agreement with the numerical prediction and good dual-band operation, with −10-dB impedance bandwidths of 13.7% and 28.3% at the resonant frequencies of 2.48 and 5.23 GHz, respectively, suitable for applications to the 2.4/5.2/5.8-GHz WLAN communication systems. Also, good monopole-like radiation patterns and antenna gains over the operating bands have been obtained. The design considerations for achieving dual-band operation of the proposed cross-slot antenna are discussed, and both theoretical and experimental results are presented.

1 Introduction

Wireless local area network (WLAN) communication systems have evolved at an astonishing rate during the last decade. This has stimulated the interest in the investigation of various WLAN antennas that are low-profile, lightweight, flush mounted and single-feed, to fit the limited equipment space of WLAN devices, and have dual- or multi-frequency capabilities to satisfy the WLAN standards in the 2.4(2.4–2.484 GHz)/5.2(5.15–5.35 GHz)/5.8(5.725–5.825 GHz)-GHz operating bands. Among the proposed designs [1–5], the planar monopole antenna has received much more interest than others, due to its potential in providing the various radiation features required for dual-band or multi-band, wide bandwidth, low profile communication systems. However, these kinds of antennas mostly need a large ground plane, which is often printed on the opposite side of the substrate from the radiating plane. Thus a via-hole connection is always necessary for feeding the signal, and this increases the manufacturing difficulty and cost.

Recently, the coplanar waveguide (CPW)-fed monopole antenna has become very popular in WLAN systems, owing to its many attractive features such as, wider bandwidth, low radiation loss, a simple structure of a single metallic layer and easy integration with WLAN integrated circuits. So far, much effort has been made to increase the bandwidth and excite the dual or multi-resonant mode of CPW-fed monopole antennas, including the CPW-fed slot monopole antenna [6, 7], the CPW-fed notched monopole antennas [8–10] and the CPW-fed meandered monopole antenna [11–13].

In this paper, we demonstrate a novel and simple design of a cross-slot monopole antenna, which gives a dual-band operation. The CPW-feed technology is applied to the design, such that only a single-layer substrate is required for this antenna, and thus fabrication is easy. In addition, owing to the embedding of a cross slot, the proposed design is not only capable of providing dual-frequency operation, but can achieve bandwidth enhancement to sufficiently cover WLAN operations at the 2.4, 5.2 and 5.8-GHz frequencies. Details of the antenna design are described, and simulation and experimental results of the input impedance and radiation characteristics of the proposed antenna are presented. Also, now the dimensional parameters of the cross slot affect the dual-band operation of the proposed antenna is studied.

2 Antenna design

The geometry of the proposed CPW-fed cross-slot planar monopole antenna for dual-band operation is shown in Fig. 1. For the design studied here, the antenna has a single-layer metallic structure and is etched on a side of an inexpensive FR4 substrate with a dielectric constant of 4.4 (ε_γ) and substrate thickness of 1.6 mm (h), whereas the other side is without any metallisation. A 50-Ω CPW transmission line, which consists of a signal strip thickness of w_f and a gap distance of d between the single strip and the coplanar ground plane, is used for feeding the antenna. Two equal finite ground planes, each with dimensions of length L_g and width W_g, are situated symmetrically on each side of the CPW feed line. The basis of the antenna structure is a rectangular patch monopole, which has dimensions of length L and width W, and is centred and connected at the end of the CPW feed line. To achieve the desired dual-band operation, the patch is embedded with a cross slot, which is horizontally centred at the patch and comprises two equal slots, each with dimensions of length $l_1 + w_s + l_2$ and width w_s, The pinch angle between the two slots is defined as θ, and the distance between the lower pinch point and bottom edge of the patch element is p. Here, l_1 and l_2 are the lengths of the resulting upper and lower sections, respectively, of one of the slots divided by the other one. The theoretical results show that

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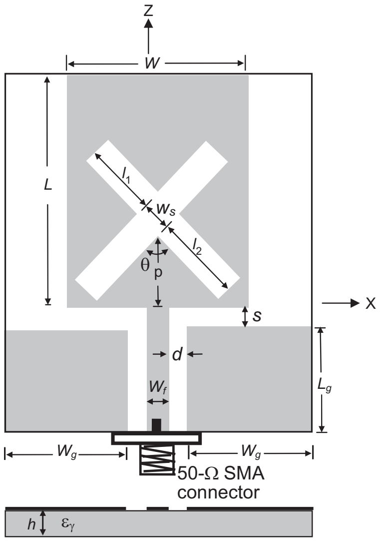

Fig. 1 *Geometry of the proposed CPW-fed cross-slot planar monopole antenna*

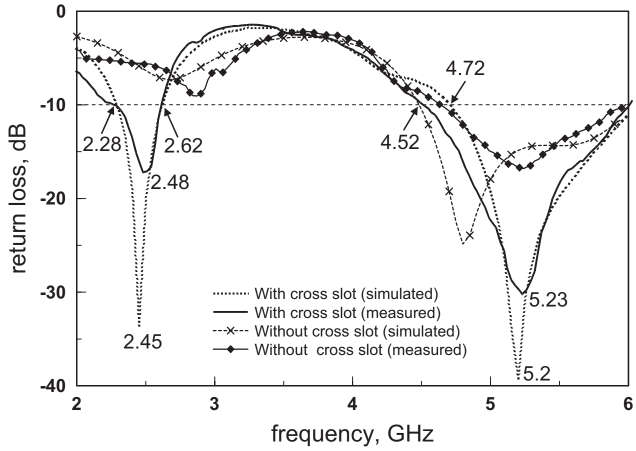

Fig. 2 *Measured and simulated return loss for the proposed dual-band CPW-fed monopole antenna shown in Fig. 1*

($L = 33.25$ mm, $W = 25.2$ mm $L_g = 14.9$ mm, $W_g = 16.7$ mm, $w_f = 3.0$ mm, $l_1 = 12.9$ mm, $l_2 = 10.8$ mm, $w_s = 4.06$ mm, $p = 9.9$ mm, $\theta = 87.2°$, $d = 2.83$ mm, $s = 3.4$ mm, $h = 1.6$ mm, $\varepsilon_\gamma = 4.4$)

the lengths l_1 and l_2 have significant effects on the resonant modes and impedance matching of the proposed antenna. In addition, the spacing between the patch and edge of the ground plane is selected as s.

To investigate the performance of the proposed antenna configurations in terms of achieving dual-band operation, a commercially available moment method code, IE3D™, was used for the required numerical analysis and to obtain the proper geometrical parameters in Fig. 1. The geometric parameters were adjusted carefully and, finally, the rectangular patch had a length L of 33.25 mm and width W of 25.2 mm, which are about $0.27\lambda_0$ and $0.21\lambda_0$, respectively, referred to the desired lower resonant frequency of 2.45 GHz. The other antenna dimensions were: $L_g = 14.9$ mm, $W_g = 16.7$ mm, $w_f = 3.0$ mm, $l_1 = 12.9$ mm, $l_2 = 10.8$ mm, $w_s = 4.06$ mm, $p = 9.9$ mm, $\theta = 87.2°$, $d = 2.83$ mm, and $s = 3.4$ mm, where w_f corresponds to the 50-Ω CPW feed line. Thus, in the following section, prototypes of the proposed antenna are constructed, and the theoretical and experimental results of the input impedance and radiation characteristics are presented and discussed. In addition, due to the theoretical results showing that the pinch angle, θ, and lengths l_1 and l_2 have significant effects on the impedance bandwidth of the proposed antenna, their influence will also be described.

3 Results and discussion

Fig. 2 shows the simulated and measured return loss against frequency for the proposed cross-slot dual-band planar CPW-fed monopole antenna. It is clearly seen that two wide operating bandwidths are obtained. The measured lower band achieves a −10-dB impedance bandwidth of 13.7%, ranging from 2.28 GHz to 2.62 GHz, with respect to the central frequency at 2.48 GHz, and the measured bandwidth for the upper mode reaches 1.48 GHz (4.52–6 GHz), or about 28.3%, referred to the central frequency at 5.23 GHz. Obviously, the antenna can operate over the bands which cover the required bandwidths of the IEEE 802.11 WLAN standards in the bands at 2.4 GHz (2400–2484 MHz), 5.2 GHz (5150–5350 MHz) and 5.8 GHz (5725–5825 MHz). We compared the measured data with the simulated results obtained from the IE3D™ electromagnetic solver. The agreement seemed very good, and a similar curve trend between the measurement and the simulative results is seen over the whole operating band, except for a very slight frequency shift and a frequency discrepancy that may be mainly due to the frequency response of the substrate permittivity. In addition, to investigate the difference with and without a cross slot, the frequency response of the return loss for the proposed antenna without a cross slot is also simulated and measured and plotted in Fig. 2. As a result, the slot-unembedded antenna only provides a good single resonant mode at the upper band with a bandwidth of 1.32 GHz (4.64–5.96 GHz) and, comparing to the case with a cross slot, there is a worse impedance matching condition of a return loss of less than −16.8 dB over the operating frequency band. It should also be noted that, for the case with cross slot, the lower resonant mode seems to exist but is not effectively excited.

The patch current distributions were than simulated using IE3D™. Fig. 3 shows the calculated patch current patterns at the two resonant frequencies, 2.45 and 5.25 GHz. For the 2.45 GHz excitation, clearly, a larger surface current distribution is observed to flow along not only the patch's edges but also the edges of the cross slot. This indicates that the embedded cross slot does effectively provide the electrical current path for producing the 2.45 GHz resonant mode. However, for the 5.25 GHz excitation, the surface currents mainly flow along the patch's edges and only a small

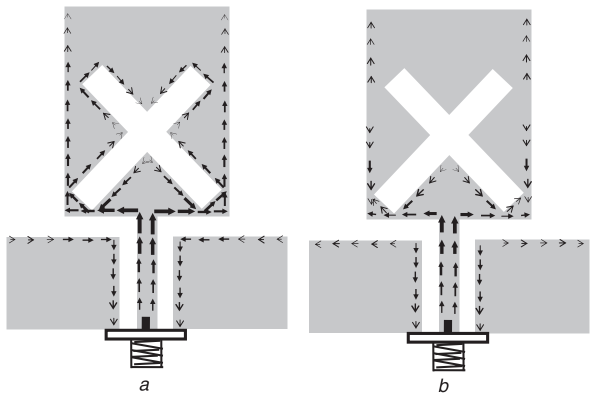

Fig. 3 *Simulated surface current distributions on the radiating patch for the proposed antenna*

a 2.45 GHz
b 5.25 GHz

current distributes over the lower edges of the added cross slot. This explains that the resonant mode of the 5.25 GHz band is not apparently affected by the cross slot. These obtained results seem to very agree with those shown in Fig. 2.

Fig. 4 shows the effect of adjusting the pinch angle θ of the cross slot to $\theta = 72^\circ$, 80°, 87.2°, 97.2° and 107.2°, on the proposed antenna's impedance matching. It is observed that, with an expansion in the pinch angle θ, the higher resonant frequency of the upper band decreases, whereas the resonant frequency and impedance bandwidth of the lower band are almost unchanged. This is due to the fact that increasing the angle of θ will lengthen the effective current path for the upper resonant mode, whereas the length of the effective current path for the lower resonant mode, which is almost along the side edge of the patch, is only slightly affected. Note that the results clearly show that the best impedance matching for both the lower and upper bands occurs when $\theta = 87.2^\circ$. In addition, since the cross slot is applied to effectively excite the dual resonant modes, an important feature of the proposed antenna is the influence of impedance matching, caused by the coupling effects between the cross slot and the embedded patch element over the two desired operating bands, especially over the higher operating band. For this, the effects of both the slot lengths l_1 and l_2 on the performance of the proposed dual-band antenna were also studied and presented in Figs. 5 and 6. In Fig. 5, the effects of varying the lengths of the upper sections of each slot, $l_1 = 9$, 11, 13, 15 and 17 mm, on the proposed antenna's impedance

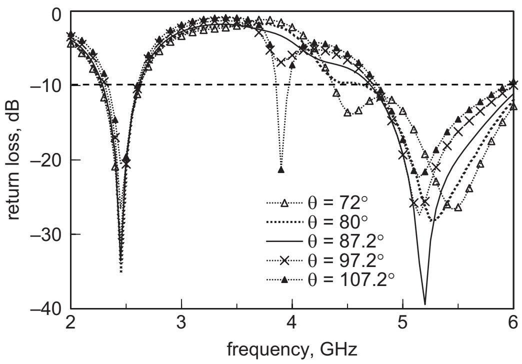

Fig. 4 *Simulated return loss for the proposed antenna, for various pinch angles (θ) of the cross slot, other parameters are the same as in Fig. 2*

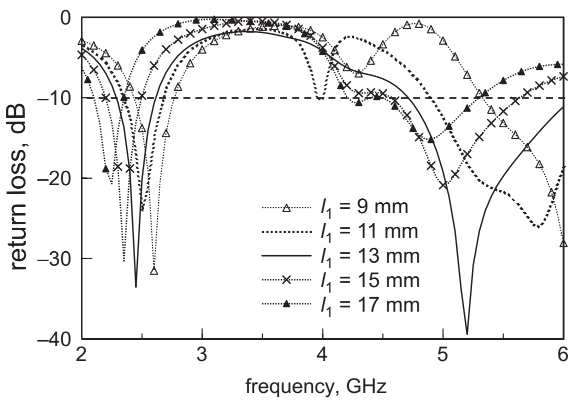

Fig. 5 *Simulated return loss for the proposed antenna for various lengths (l_1) of the cross slot, other parameters are the same as in Fig. 2*

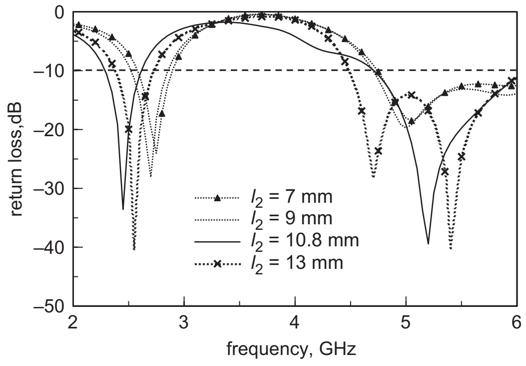

Fig. 6 *Simulated return loss for the proposed antenna for various lengths (l_2) of the cross slot, other parameters are the same as in Fig. 2*

matching, are theoretically illustrated. It is observed that, with an increase in the length l_1, the resonant frequencies of both the lower and upper bands move toward the lower frequencies. This is probably due to the increase in the length of l_1 extending the effective current paths for both the lower and upper resonant modes. Also note that, the impedance matching condition over the upper frequency band is found to be sensitively affected by the length of l_1, and, in this case, the optimal matching conditions for the proposed antenna over both the lower and upper bands have been obtained when l_1 is selected to be 13 mm. As for the effect of the length of l_2 on the proposed antenna's impedance matching, the simulated results, as shown in Fig. 6, were obtained by use of $l_2 = 7$, 9, 10.8 and 13 mm. It is clearly seen that a similar situation occurs, as that affected by l_1.

Typical radiation characteristics of the frequencies across the lower and upper bands for the proposed dual-band CPW-fed cross-slot monopole antenna are also examined. Figs. 7–9 show, respectively, the measured (solid line) and simulated (dotted line) radiation patterns, including the vertical (E_θ) and the horizontal (E_ϕ) polarisation patterns cut in the azimuth ($x-y$) plane and cut in the elevation ($x-z$ and $y-z$) planes for the antenna at the lower band of

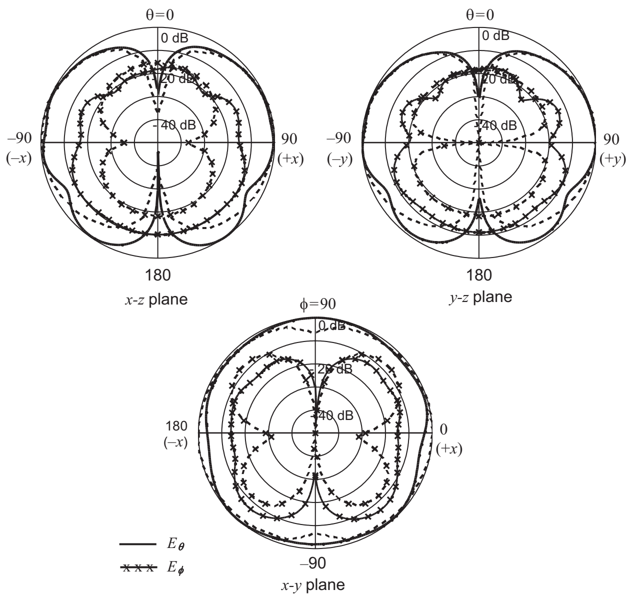

Fig. 7 *Measured (solid line) and simulated (dotted line) radiation patterns at 2.45 GHz for the proposed dual-band CPW-fed cross-slot monopole antenna studied in Fig. 2*

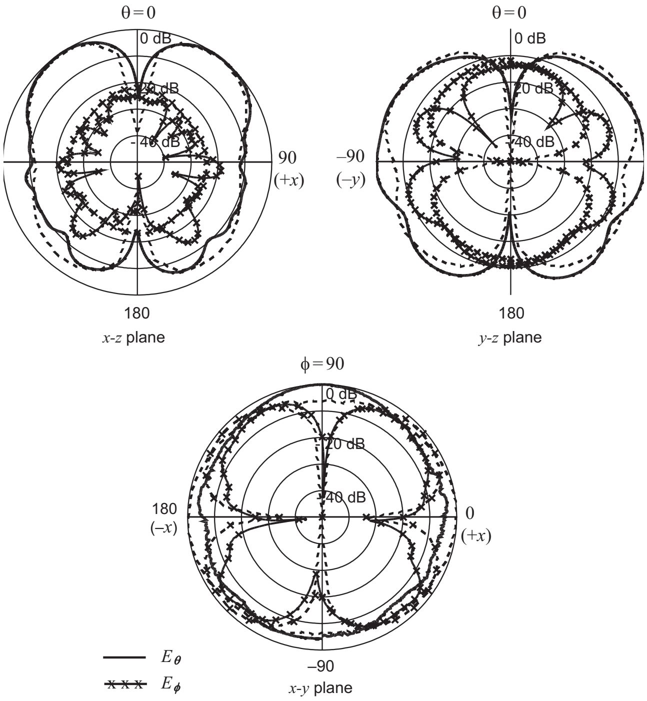

Fig. 8 *Measured (solid line) and simulated (dotted line) radiation patterns at 5.25 GHz for the proposed dual-band CPW-fed cross-slot monopole antenna studied in Fig. 2*

2.45 GHz, and at the upper bands of 5.25 and 5.75 GHz. The patterns are observed to be stable for operating at the three frequencies. Similar to a monopole antenna, which has a good omni-directional pattern in the azimuth plane and conical radiations in the elevation planes, the measured patterns, in the $x-y$ plane, are all nearly omnidirectional, and those in the $x-z$ and $y-z$ planes, as expected, are all very monopole-like. Also note that, measurements at other operating frequencies across the bandwidth of each band show radiation patterns similar to those plotted here. That is, stable radiation patterns have been obtained for the

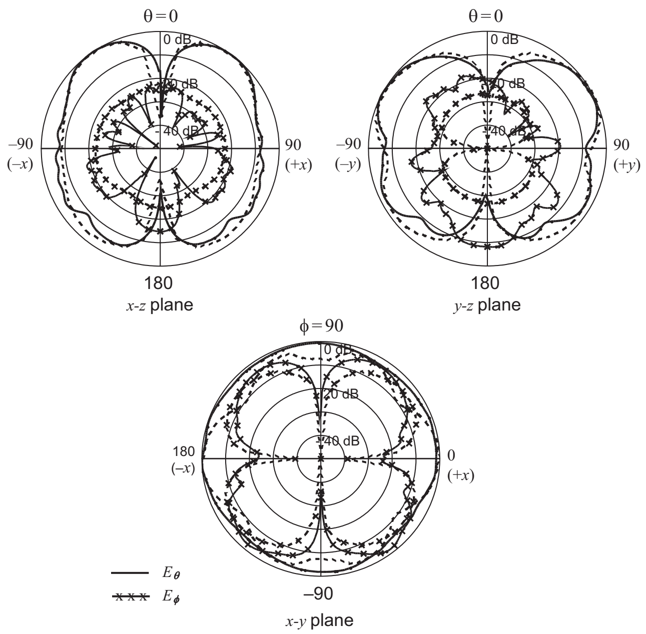

Fig. 9 *Measured (solid line) and simulated (dotted line) radiation patterns at 5.75 GHz for the proposed dual-band CPW-fed cross-slot monopole antenna studied in Fig. 2*

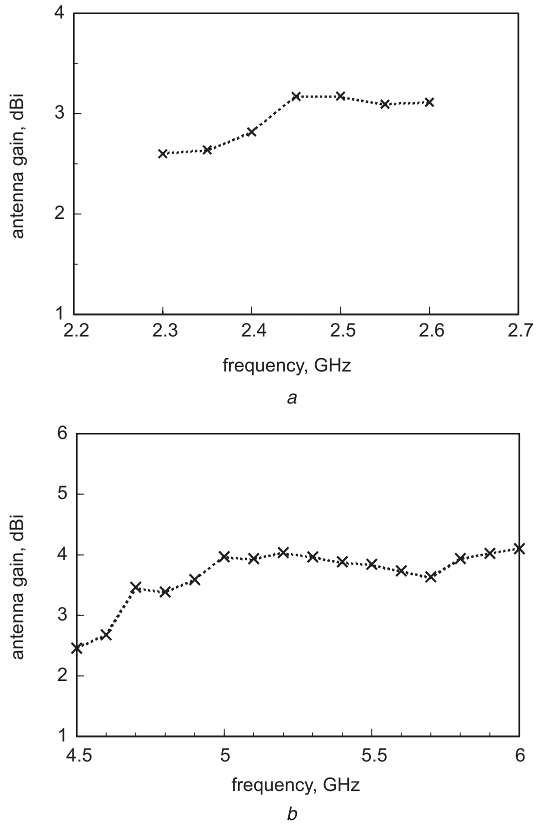

Fig. 10 *Measured peak antenna gain for frequencies across the lower band and the higher band for the proposed dual-band CPW-fed cross-slot monopole antenna studied in Fig. 2*

a 2.28–2.62 GHz
b 4.52–6.00 GHz

proposed antenna. Finally, the measured antenna gain against frequency for the proposed antenna across the two bands is shown in Fig. 10. For the lower band, the antenna has a maximum radiation gain of about 3.17 dBi in the broadside direction, with gain variations less than 0.5 dBi, whereas for the higher band, the antenna gain is within a range of 2.5–4.5 dBi.

4 Conclusion

A CPW-fed planar monopole antenna with a cross slot for dual-band operation has been designed and successfully implemented, with experimental and numerical results. With the insertion of a cross slot into the patch, the proposed antenna can provide sufficient impedance bandwidths and suitable radiation characteristics to be applied in the 2.4/5.2/5.8-GHz WLAN systems. Also, measurements of the constructed prototypes showed good agreement with the simulated data, and the large effects of varying the slot parameters on the antenna resonant frequencies and impedance bandwidths have also been examined.

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