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Research Article

A Codesigned Compact Dual-Band Filtering Antenna with PIN Loaded for WLAN Applications

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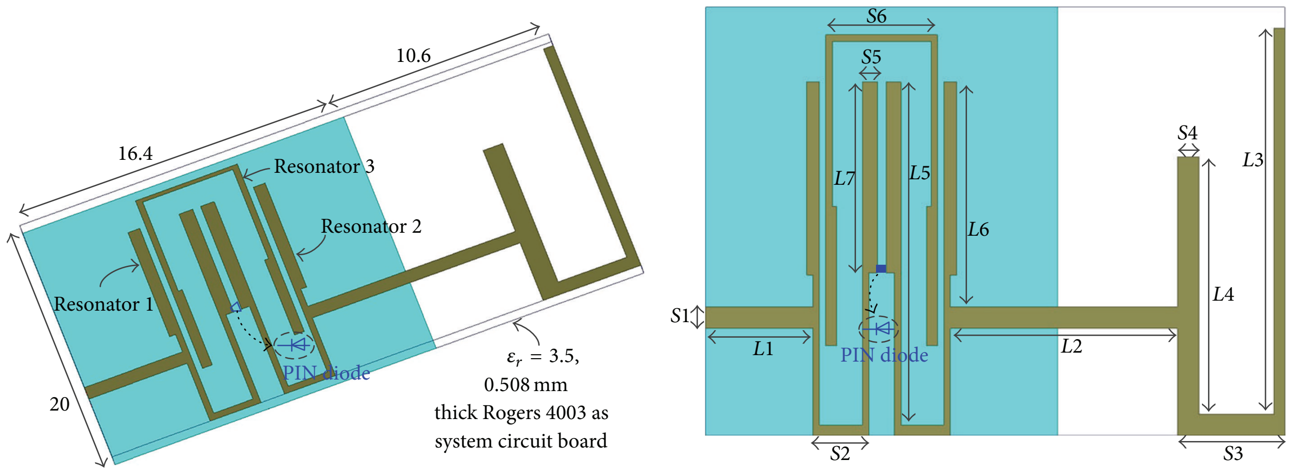
A codesigned compact dual-band filtering antenna incorporating a PIN diode for 2.45/5.2 GHz wireless local area network (WLAN) applications is proposed in this paper. The integrated filtering antenna system consists of a simple monopole radiator, a microstrip dual-band band-pass filter, and a PIN diode. The performance of the filtering antenna is notably promoted by optimizing the impedance between the antenna and the band-pass filter, with good selectivity and out-of-band rejection. The design process follows the approach of the synthesis of band-pass filter. In addition, the PIN diode is incorporated in the filtering antenna for further size reduction, which also widens the coverage of the bandwidth by about 230% for 2.4 GHz WLAN. With the presence of small size and good filtering performances, the proposed filtering antenna is a good candidate for the wireless communication systems. Prototypes of the proposed filtering antenna incorporating a PIN diode are fabricated and measured. The measured results including return losses and radiation patterns are presented.

1. Introduction

The wireless local area network (WLAN) has experienced a rapid growth in the last decade, which has been widely employed in wireless applications such as WIFI, Bluetooth, and GPS. For further portability and better user experiences, the size reduction has been a trend in the wireless system designs. Generally, antennas and filters are considered as the critical components in reducing the whole sizes of the radio frequency (RF) front ends. In addition, the filter is usually connected right after the antenna, and the direct connection between them may induce additional mismatch losses and deteriorates the performances of the filter. Therefore, the integration of the antenna and the filter will be of great interest, which can provide both desired filtering and radiating functions.

Several efforts have been proposed in the literature [1–13] to integrate the antenna and the filter into a single module, and the sizes as well as operating bands are summarized in Table 1 [1–8]. The integration of the open-loop resonator loaded filter and the monopole antenna is presented in [3], which reduces the size of the filtering antenna by employing the antenna structure as the last resonator of the filter. The synthesis technique has been comprehensively studied in [2, 8], which is proved to be feasible by the example of an integrated 2.45 GHz third-order filtering antenna with good band-edge selectivity and design accuracy. What is more, compared to the traditional way of connecting the antenna and the filter by standard 50 Ω ports, the filtering antenna in [2, 8] reduces the transition loss to be near zero. For further reduction of the footprint of the integrated filtering antenna system, the integration of slot antenna and vertical cavity filter has been proposed in [7]. However, most of the referred filtering antennas are for single-band applications, which can hardly meet the demands of the current dual-band 802.11 a/b/g WLAN applications.

In this paper, a compact dual-band filtering antenna with printed structure for wireless communication systems is



(a) (b)

Figure 1: The proposed filtering antenna configuration. (a) Geometry of the dual-band filtering antenna. (b) Detailed dimensions of the filtering antenna ($L1 = 5$; $L2 = 10.6$; $L3 = 185$; $L4 = 12$; $L5 = 16$; $L6 = 10.5$; $L7 = 8.9$; $S1 = 1$; $S2 = 2.6$; $S3 = 5$; $S4 = 1$; $S5 = 1.8$; $S6 = 5.2$;). All dimensions are in millimeters.

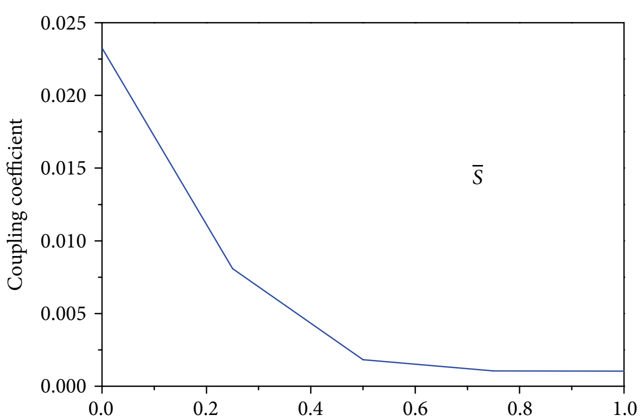


Figure 2: Coupling coefficient k as a function of the distance between resonator 1 and resonator 2.

Table 1: Comparison of the sizes of the filtering antenna.

Reference number	Total size	Operating bands	Type of the substrate
[1]	$12.9 \times 6.5\,mm^2$	X-band	Rogers 5880
[2]	$60 \times 60\,mm^2$	2.4 G WLAN	Rogers 4003
[3]	$30 \times 45\,mm^2$	2.4 G WLAN	$\varepsilon_r = 2.65$
[4]	$10.9 \times 10.9\,mm^2$	Ku-band	$\varepsilon_r = 2.54$
[5]	$30 \times 20\,mm^2$	4.06~4.26 GHz	
[6]	$18 \times 20\,mm^2$	4.7~5.2 GHz	$\varepsilon_r = 3.38$
[7]	$12.5 \times 9\,mm^2$	10~10.5 GHz	$\varepsilon_r = 3.48$
[8]	$65.2 \times 50\,mm^2$	2.4 G WLAN	$\varepsilon_r = 3.38$

proposed. The filtering antenna is integrated by a microstrip dual-band band-pass filter and a simple monopole antenna, which is conducted by utilizing the synthesis approach. Without restricting the impedance between the filter and the antenna to 50 Ω, the performances of the filtering system are promoted and the total loss of the filtering antenna is almost the same as the filter insertion loss. The presented filtering antenna has a whole size of $27 \times 20\,mm^2$, which is much smaller compared to the antenna referred to in [3]. To widen the bandwidth of the filtering antenna, reconfigurable technology [14–18] has been applied, which usually expands the bandwidth by combining different working states with a fixed size. In particular, the PIN diode is incorporated in the filtering antenna system, which covers the dual-band 2.45/5.2 GHz WLAN by combining the two working states. Fabrication of the printed filtering antenna is easy and of low cost, while the integrated filtering antenna has good band-edge selectivity and flat antenna gain. Measured radiation characteristics of the proposed filtering antenna are presented.

2. Design of the Filtering Antenna

Figure 1 depicts the layout of the proposed integrated filtering antenna, which is printed on a low-cost two-side printed substrate with relative dielectric constant of 3.5 and a thickness of 0.508 mm. The filtering antenna system includes three resonators of high Q values and one monopole antenna. The dual-band filtering antenna has a total size of $27 \times 20\,mm^2$, which is realized due to the introduction of the PIN diode and is quite promising for wireless communication systems. Note that the dual-band band-pass filter is directly connected to the antenna, and the mismatch loss is correspondingly reduced.

2.1. Synthesis of the Dual-Band Filtering Antenna. A two-pole dual-band band-pass filter with a bandwidth of 30 MHz with centre frequency at 2.45 GHz and 435 MHz with centre frequency at 5.2 GHz is synthesized according to the dual-band filter synthesis technique [2]. The dual-band filter consisting of three stepped impedance resonators is printed on the 0.508 mm Rogers 4003 substrate. The value of the coupling coefficients $k12$ between resonator 1 and resonator 2 is 0.02, while the value of the external quality factors is 53.07.

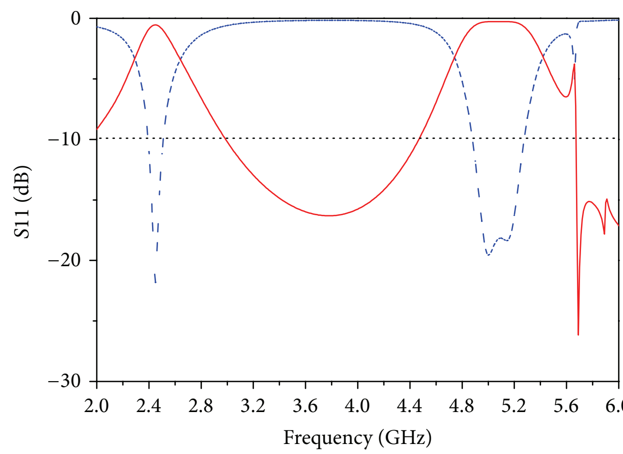


FIGURE 3: Simulated S parameters of the dual-band filter.

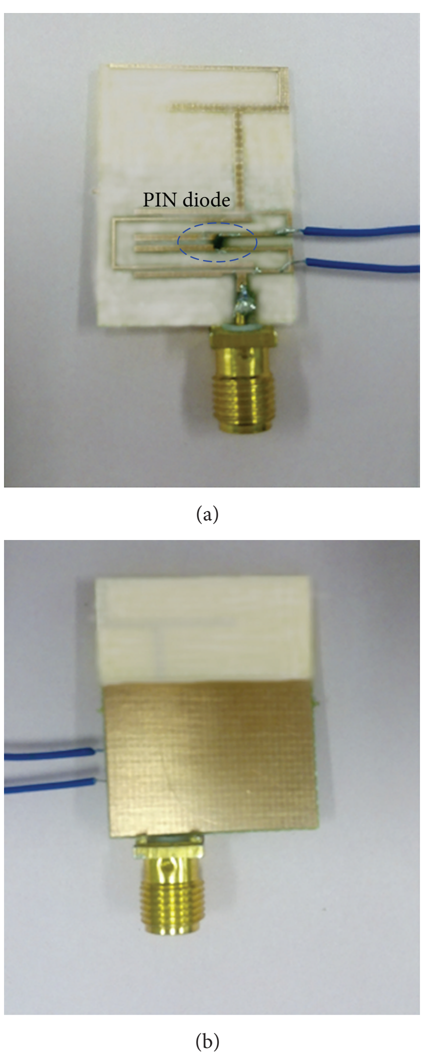


FIGURE 4: Photos of the manufactured dual-band filtering antenna for 2.45/5.2 GHz WLAN applications.

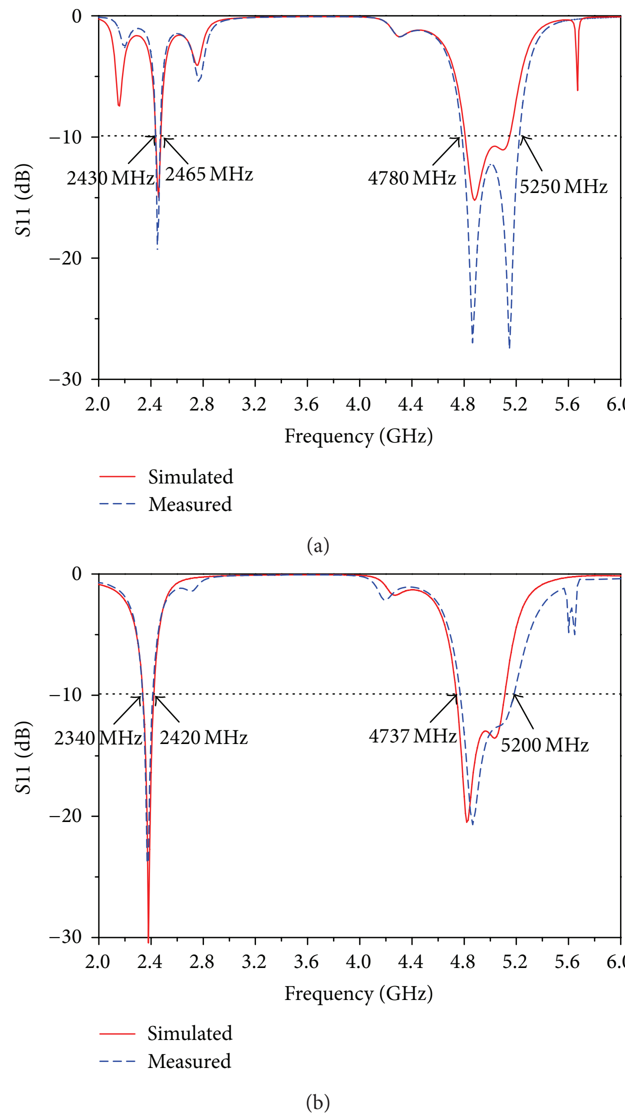


FIGURE 5: Simulated and measured reflection coefficient against frequency for the proposed filtering antenna: (a) for state1 and (b) for state2.

The referred coupling coefficient $k12$ depends on the relative distance of resonator 1 and resonator 2. The smaller the value of S is, the stronger the coupling between the resonators is.

The coupling coefficient k is calculated based on the following equation:

$$|k| = \left|\frac{f_1^2 - f_2^2}{f_1^2 + f_2^2}\right|, \quad (1)$$

where f_1 and f_2 represent the eigenfrequencies of resonator 1 and resonator 2, respectively, which can be obtained through the optimization of the relative distance S between the resonators. The coupling coefficient as a function of the distance S between resonator 1 and resonator 2 is depicted in Figure 2. The optimized dimensions of the filter are given before, and the simulated $S11$ and $S21$ of the filter are plotted in Figure 3.

The dual-band two-strip monopole antenna which is designed based on the fixed ground plane has a size of 10.6 ×

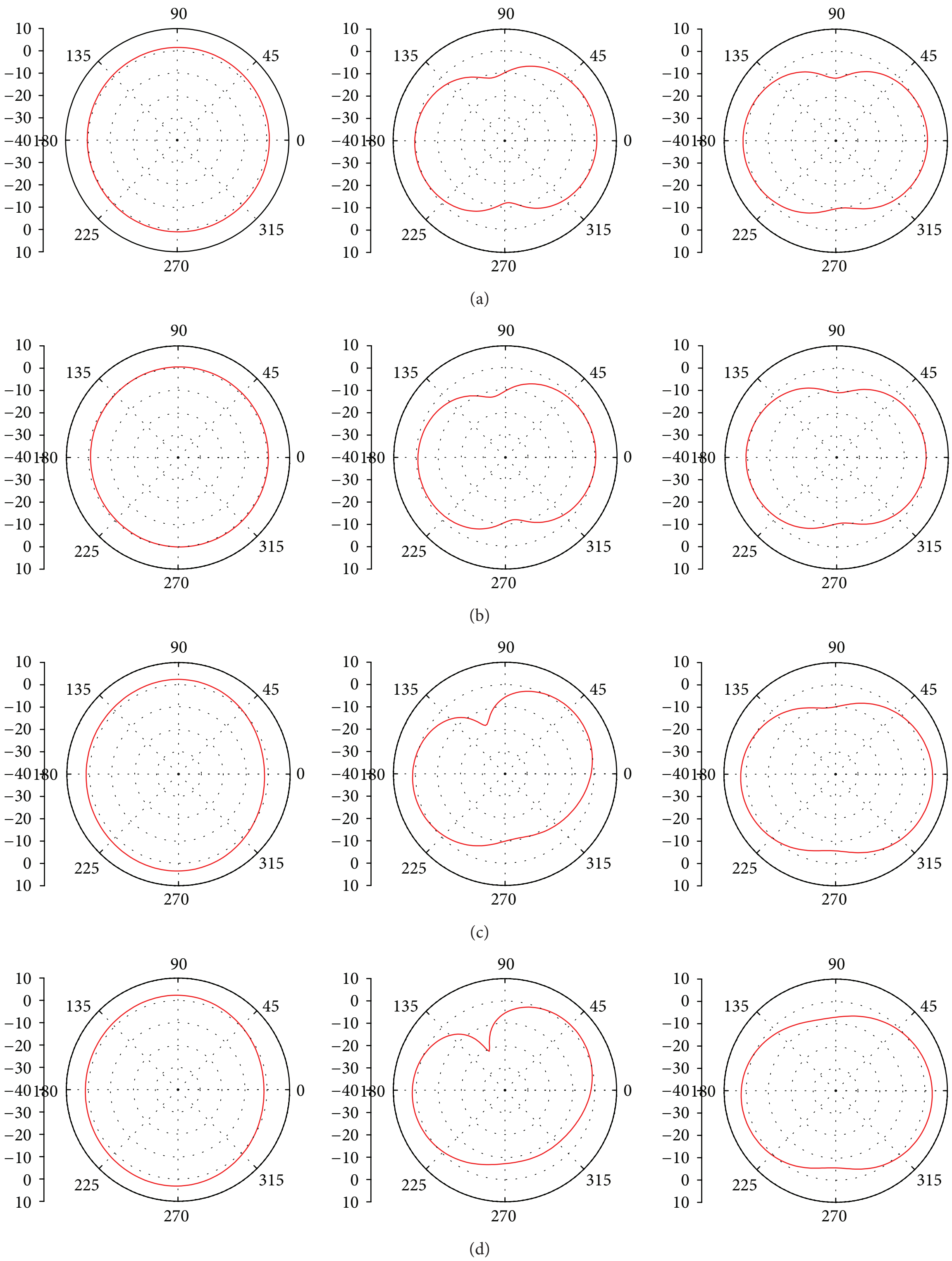


Figure 6: Measured 2D radiation patterns. (a) 2400 MHz; (b) 2450 MHz; (c) 5000 MHz; and (d) 5200 MHz for the proposed filtering antenna.

$20\,mm^2$. The resonant frequencies are mainly determined to its total length, namely, the length of ($L2 + L3 + S3$). The lengths of the long strip (34.6) and the short strip (13.6 mm) are approximately a quarter-wavelength for 2.45 GHz and 5.2 GHz, respectively. The connecting line between the filter and the antenna is optimized, whose dimension is finally identified as 10.6 mm in length and 1.1 mm in width.

2.2. Implementation of the Reconfigurable Technology. To achieve larger bandwidth coverage, the PIN diode is incorporated in the filtering antenna, which is located in the coupling structure of the filter. As a result, the bandwidth of the filtering antenna is expanded with a fixed size. When the PIN diode is OFF (state1), the PIN diode is equivalent to a series capacitance with high isolation and the filtering antenna works in the previously mentioned state, covering the 2425–2465 MHz and 4785–5220 MHz. When the PIN diode is ON (state2), it works as a series resistance; then resonator 2 and resonator 3 are directly connected; thus the path of the currents is changed and the resonant frequencies are shifted towards lower frequencies, covering the 2340–2430 MHz and 4740–5100 MHz. Therefore, by combining the two working states, the bandwidth of the filtering antenna is increased by about 40% with the addition of the PIN diode, covering the 2.45/5.2 GHz WLAN operation. The prototype is fabricated under the consideration of the PIN diode and its DC bias circuit.

3. Results and Discussion

The proposed dual-band filtering antenna system was fabricated and tested. Photos of the fabricated filtering antenna system and the PIN diode as well as its corresponding DC are shown in Figure 4. The simulated results of the integrated filtering antenna are achieved based on the HFSS 13.0, while the measured results are given by using the Agilent N5247A network analyzer and the Satimo StarLab far field measurement system. Simulated and measured $S11$ against the frequency for the two working states are shown in Figure 5. Type of the PIN diode is selected as Philips BAP64-03, while the DC bias current is supplied by two AAA batteries. The filtering antenna successfully changes its working states to widen the bandwidth by nearly 80 MHz (230%) for 2.4 GHz WLAN and 49 MHz for 5.2 GHz WLAN. The measured results show that the presented filtering antenna provides good selectivity and out-of-band rejection.

Measured radiation patterns for the proposed filtering antenna system in the x-z, y-z, and x-y planes are shown in Figure 6, which is conducted at 2400 and 5000 MHz for state1 as well as 2450 and 5200 MHz for state2. For all the different frequencies for the two working states, the measured radiation patterns are dipole-like, which are nearly omnidirectional in the azimuth plane for the two bands.

4. Conclusion

In this paper, a small-size dual-band filtering antenna incorporating the PIN diode is proposed. The presented filtering antenna system is printed on the low-cost substrate and occupies a total size of $20 \times 27\,\text{mm}^2$. Through the incorporation of the PIN diode, the bandwidth of the filtering antenna is increased by nearly 230% for 2.4 GHz WLAN, covering the dual-band 2.45/5.2 GHz WLAN operation. Performance of the filtering antenna system is promoted through the optimization of the impedance between the filter and the monopole antenna. In addition, by directly connecting the antenna and the filter, the mismatch loss is greatly reduced. According to the measured results, the proposed filtering antenna system has good selectivity and out-of-band rejection, which prove that the filtering antenna is applicable for the RF front end for modern wireless systems.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

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