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A SIMPLE FILTERING-ANTENNA WITH COMPACT SIZE FOR WLAN APPLICATION

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Abstract—This paper presents a simple microstrip filtering-antenna with compact size for WLAN application. The T-shape resonator through an inset coupling structure can be treated as the admittance inverter and the equivalent circuit of the filtering-antenna is exactly the same as the bandpass filter prototype. With a little extra circuit area, the proposed filtering-antenna has almost twice wider bandwidth, good skirt selectivity and high suppression in the stopband compared to the conventional microstrip antenna.

1. INTRODUCTION

With its low profile, easy fabrication, microstrip antennas are widely used in modern wireless communication. Miniaturization is a major challenge to RF front ends design. One way to miniaturize RF front ends is to integrate the filtering and the radiating functions into just one module. There have been several efforts in the literature for integrating the filter and the antenna into a single module. In [1, 2], the filter and the antenna are integrated into a single microwave de. However, an extra impedance transformation structure was used in between the filter and the antenna so that increase the complexity of the overall system, together with its weight, and losses. A co-design approach has been proposed to incorporate the filter and the antenna [3–6]. This integration approach reduces the filter-antenna size and the transition loss between the filter and the antenna.

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However, the filter-antennas did not show good filter performance — especially the band-edge selectivity and vice for size reduction stopband suppression in [3,4] and the admittance inverters of the filter-antennas in [5] and [6] were difficult to synthesize. The filtering antennas were also achieved by different forms, such as circular patch antennas [7], slot dipole antennas [8] and monopole antennas [9,10]. In [9], a Γ-shaped monopole antenna is proposed, which achieves the purpose of the high band-edge selectivity, but the coupled line resonator is needed. In the authors' previous work [10], the microstrip square open-loop resonators are designed for integrating with a Γ-shaped antenna to be a filtering-antenna.

In this paper, we propose a design of a compact microstrip antenna with a simple filtering structure. Using a T-shape resonator through an inset coupling structure, the equivalent circuit of the filtering-antenna is exactly the same as the bandpass filter prototype, since the antenna can be designed with the filter response. With a little extra circuit area, the proposed filtering-antenna has almost twice wider bandwidth, good skirt selectivity as the conventional bandpass filter, flat antenna gain in the passband, and high suppression in the stopband compared to the conventional microstrip antenna. Details of the antenna design and the measured performance are given.

2. FILTERING-ANTENNA STRUCTURE DESIGN

The design evolution of the proposed filtering-antenna and its corresponding equivalent circuit are presented in Figure 1. It begins with the design of the microstrip antenna denoted as Antenna 1, which consists of a circular patch and a 50 ohm microstrip line as shown in Figure 1(a). The equivalent circuit model of the microstrip antenna (Antenna 1) can be expressed by a parallel inductor-capacitor-resistance (L-C-R_L) as shown in Figure 1(d) [11], which R_L noted as the radiating resistance of the antenna. By separating the patch and the feeding microstrip line in Antenna I, the Antenna II including the parallel coupled lines with length of $\lambda/4$ is formed as shown in Figure 1(b) and the coupled line with length of $\lambda/4$ can be modeled by a J (admittance) inverter as shown in Figure 1(e) [12]. Finally, the proposed filtering antenna (Antenna III) is obtained by locating two horizontal arms extended in the x-direction in the Antenna II, thus a T-shaped resonator composed of a vertical arm and two horizontal arms is introduced as shown in Figure 1(c). With length of $\lambda/2$, the vertical arm and a horizontal arm can be modeled as an open $\lambda/2$ transmission line, and its equivalent circuit is modeled by the parallel L-C as shown as in Figure 1(f) [12]. From the Figure 1(g), it can be clearly seen that the equivalent circuit of the proposed filtering-antenna is exactly the same as the second-order bandpass filter prototype, so the antenna can be designed with the filter response.

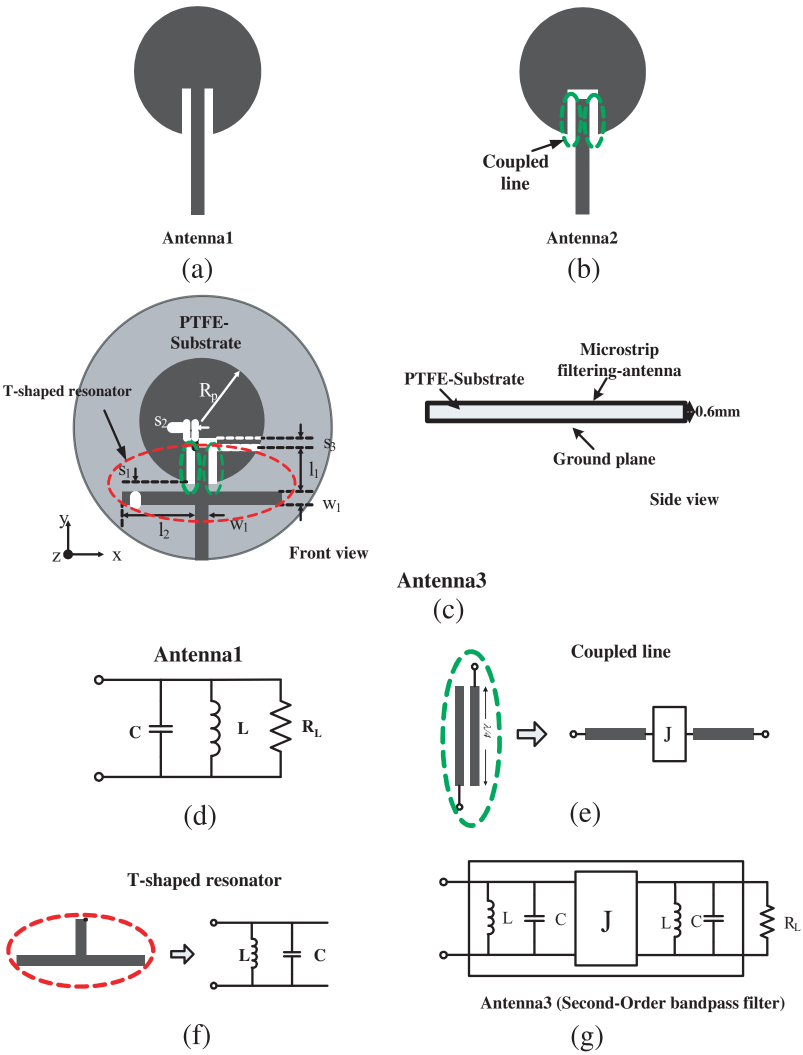

Figure 1. Design evolution of the proposed filtering-antenna and the corresponding equivalent circuits.

The detailed structure parameters of the proposed filtering antenna are presented in the Figure 1(c), which printed on the PTFE dielectric substrate with thickness of 0.6 mm, and relative permittivity

2.65. The ground plane with radius of 24.6 mm is printed on the back side of the substrate which has the same size as the substrate. The circular patch has a radius of Rp, with Rp about $0.3\lambda_g$ at the operating frequency (5.75 GHz). The vertical arm of the T-shape resonator is inset into the circular patch in the y-direction with length l_1 (about $\lambda_g/4$ long) and width w_1, which has the gaps apart the patch of s_1, s_2 and s_3; the other two horizontal arms are extended in the x-direction with length l_2 and width w_1, which $l_1 + l_2$ is about $\lambda_g/2$ long. The feeding 50-ohm microstrip line with width w_1 is inserted at the bottom. In particular, compared to the conventional microstrip antenna, the dimension of the filtering-antenna is slightly larger. The final optimal antenna parameters are shown in Table 1.

Table 1. Dimensions of the proposed antenna.

Parameters	w_1	s_1	s_3	R_p	s_2	l_1	l_2
Values/mm	1.64	1.8	1.47	9.57	1.25	6.83	11.25

3. SIMULATED RESULTS AND DISCUSSION

The simulated reflection coefficient and broadside ($+z$) direction antenna gain obtained for the filtering-antenna is compared to the conventional microstrip antenna in Figure 2. According to the results, it is found that with the center frequency at 5.75 GHz, the filtering-antenna possesses two transmission poles at 5.72 GHz and 5.81 GHz, provides twice wider bandwidth range of 5.68–5.85 GHz compared to the conventional microstrip antenna, making it is suitable for WLAN application. Also observe that, the filtering-antenna exhibits a constant radiation gain over the required frequency bandwidth, and has two radiation nulls at 5.24 GHz and 6.05 GHz, which has much better stop-band suppression and band-edge selectivity. It is illustrated that by using a T-shape resonator through an inset coupling structure the proposed antenna has a better filtering performance.

With a better performance of reflection coefficient and broadside ($+z$) direction antenna gain, the radiation characteristics of the proposed filtering-antenna is almost invariant compared to the conventional microstrip antenna. Figure 3 presents the simulated radiation pattern of the conventional microstrip antenna and the filtering-antenna at 5.82 GHz in the xoz-plane and yoz-plane. It can be seen that the two kinds of antenna patterns in the direction of the main lobe is consistent, so the introduced T-shaped resonator for the filtering antenna does not affect a lot on the radiation pattern. But due to the increase of new loss structure, the peak gain for the filtering antenna is smaller 0.14 dB than that for the conventional microstrip antenna.

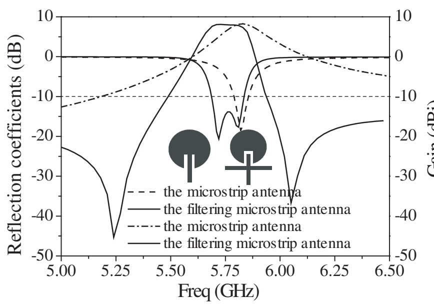

Figure 2. Simulated reflection coefficient and gain of the microstrip antenna and the filtering-antenna.

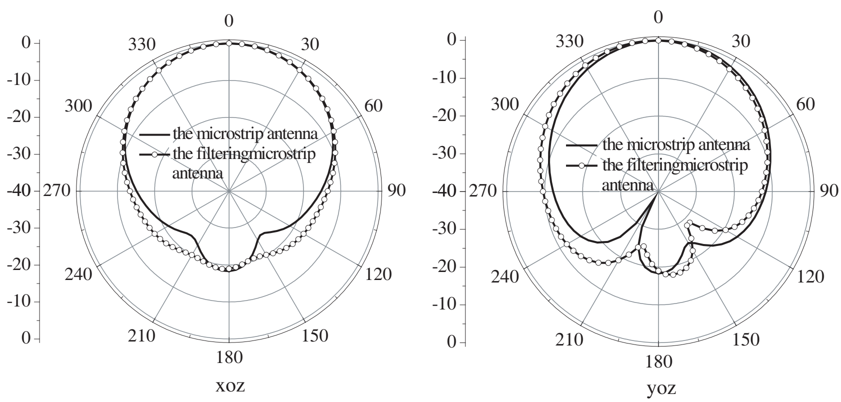

Figure 3. Simulated radiation patterns for the microstrip antenna and the filtering-antenna.

In order to further study the operation property of the proposed filtering-antenna, effects of the distance between the coupled line (S_2) on the impendence are studied. Figure 4 presents the simulated normalized input impedance and reflection coefficient for S_2 varied from 1.05 to 1.45 mm; other dimensions are the same as given in Table 1. It is seen that the impedance characteristics of the filtering-antenna is strongly affected by S_2. From Figure 4(a), it can be seen that with an increase in S_2, the crossover pattern gets smaller near the centre matching point, which illustrated that the space between the two resonate points gets smaller own to the weak coupling between the coupled line. This phenomenon can also be seen from Figure 4(b) that two resonate frequencies are in the close with the increase of S_2. With $S_2 = 1.25\,\text{mm}$, the optimal results are obtained for the proposed filtering antenna.

Effects of the T-shaped resonator on the impendence of the filtering-antenna are also studied. Figure 5 shows the simulated normalized input impedance and reflection coefficient as a function of the length l_1 for the vertical arm of the T-shape resonator; other dimensions are the same as given in Table 1. Results for the length

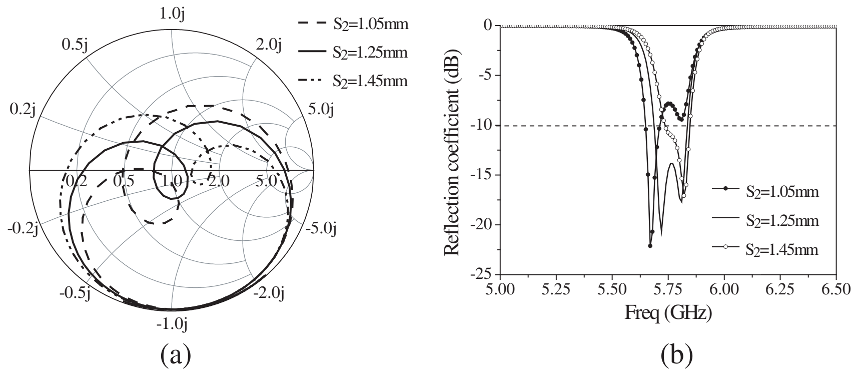

Figure 4. Simulated (a) input impedance (b) reflection coefficient for different values of S_2.

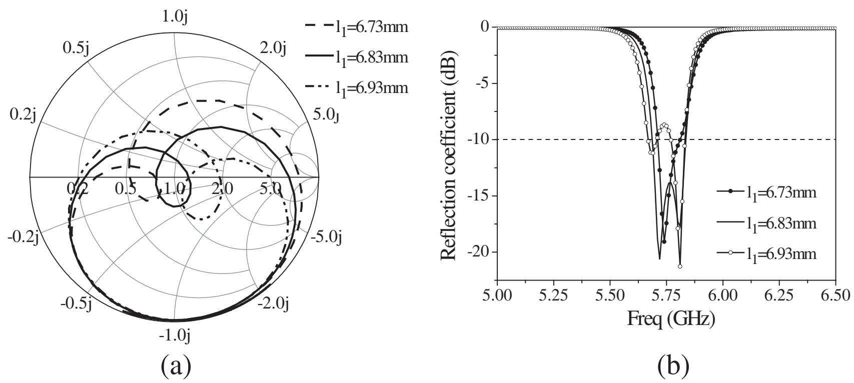

Figure 5. Simulated (a) input impedance (b) reflection coefficient for different values of l_1.

l_1 varied from 6.73 to 6.93 mm, and large effects on the impedance matching of the resonant modes are seen. When the length l_1 increases, the crossover pattern gets larger near the centre matching point as shown in Figure 5(a), which illustrated that the space between the two resonate points gets larger that also can be seen in Figure 5(b). These results indicate that by adjusting the dimension of the T-shaped resonator, the operation bandwidth of the proposed filtering antenna can be controlled. With $l_1 = 6.83$ mm, the optimal results are obtained for the proposed filtering antenna.

4. MEASURED RESULTS

A prototype of the proposed filtering antenna was fabricated according to the dimensions given in Table 1 as shown in Figure 6. The Agilent 8722D vector network analyzer and the Satimo StarLab far field measurement system were used for measurement. The measured reflection coefficient and gain of the filtering-antenna are compared to simulated results in Figure 7. The measured reflection coefficient is below −10 dB across the entire bandwidth range of 5.71–5.88 GHz and the filtering-antenna exhibits a constant radiation gain over the required frequency bandwidth which has two radiation nulls at 5.28 GHz and 6.14 GHz, which agree with the simulated bandwidth well. The measured peak gain is 8.06 dBi at 5.78 GHz, which is also very close to the simulated 8.1 dBi.

Figure 6. Photograph of the proposed filtering-antenna.

In order to further study the reason for the production of the radiation nulls at the frequencies of 5.28 and 6.14 GHz, surface current distributions are given in Figure 8. It can be clearly seen from the Figure 8(a) that the current is weak in the circular patch radiator and mainly distributed in the two horizontal arms of the T-shaped

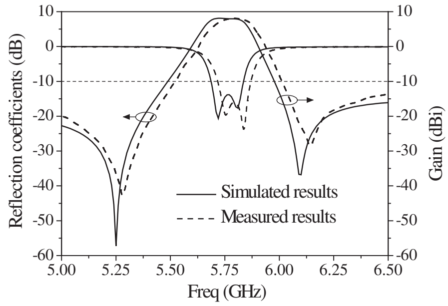

Figure 7. Simulated and measured reflection coefficient and gain of the proposed filtering-antenna.

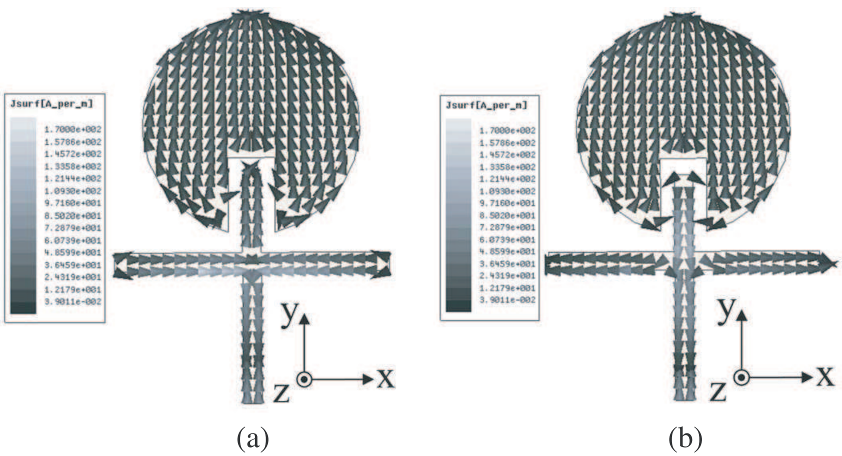

Figure 8. Simulated surface current distributions at (a) 5.28 GHz, (b)6.14 GHz.

resonator and the microstrip feedline. In addition, the current strength in the two horizontal arms is equal but the directions in opposite; thus the radiation in the direction of maximum radiation ($+z$ axis) is offset almost, which is explained that the appearance of the first radiation null at the 5.28 GHz. From the Figure 8(b) it also can be seen the current distribution at 6.14 GHz is almost similar with that at 5.28 GHz, which is also illustrated the weak radiation at 6.14 GHz.

The measured total-field radiation patterns at 5.82 GHz in the xoz-plane and yoz-plane are presented in Figure 9. The results show this antenna has a stable directional radiation pattern and the 3 dB beamwidth in these two planes both are about 65 degree.

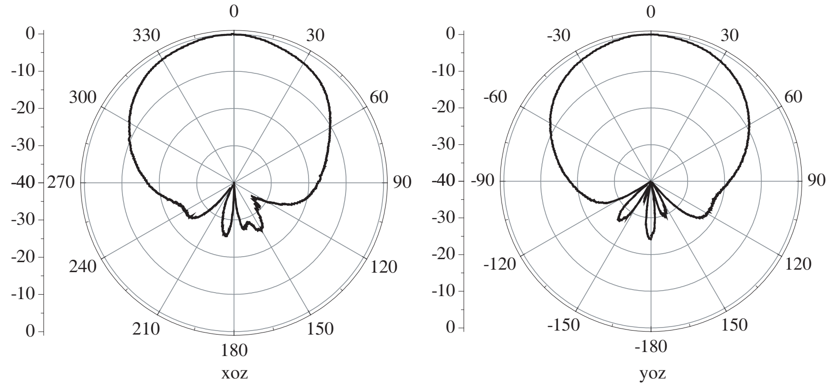

Figure 9. Measured radiation patterns of the proposed filtering-antenna.

5. CONCLUSION

The good performance of a simple filtering-antenna with a compact size is proposed. The antenna can be designed with the filter response. A twice wider bandwidth is achieved and the good skirt selectivity, flat antenna gain in the passband, and high suppression in the stopband are also provided. Owing to these results, the proposed filtering-antenna is very suitable for use in the RF front end that is essential for WLAN application.

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