Compact Filtering Antenna Based on Dumbbell-Shaped Resonator

Xueliang Min* and Hou Zhang

Abstract—A filtering antenna based on a dumbbell-shaped resonator is proposed, fabricated and measured. A Γ-shaped antenna and the proposed dumbbell-shaped resonator are used and integrated to be a filtering antenna. The Γ-shaped antenna which acts as a radiator is excited by a coupled line. Measured results show that the filtering antenna achieves an impedance bandwidth of 6.7% at a reflection coefficient $|S_{11}| < -10\, \text{dB}$ and has a gain of 1.35 dBi. Moreover, a radiation zero occurs at 3.1 GHz. Compared with the characteristics of fundamental Γ-shaped antenna, the design of the dumbbell resonator has little impact on antenna’s radiation patterns. In addition, to explain the mechanism of filtering antenna, the analysis of surface current distribution on patch is given. The size of filtering antenna is $0.33\lambda_0 \times 0.17\lambda_0$ ($\lambda_0$ is the free-space wavelength at 2.45 GHz). Compared to other recent works, a simpler structure and more compact size are the key features. Owing to the operating bandwidth and the characteristic of filtering, the proposed antenna can be used in modern wireless communications systems.

1. INTRODUCTION

In recent years, with the rapid development of wireless communications systems, the requirements for miniaturization and improved performance in microwave fronts ends are demanded. Integrating multiple functional circuitries into one device is one of the focusing issues. In most of the RF front ends, the antenna and bandpass filter are independent components. The function of the antenna is receiving and transmitting signal, and the bandpass filter is used to filter spurious signals. In general, these two components are designed separately [1–3], but many scholars start to study the co-design method and other methods to realize filtering antennas [4–15]. Filtering antennas not only improve the performance of communications systems, but also minimize the total size. In [4], a compact printed filtering antenna with high band-edge gain selectivity is presented. The proposed structure serves as a radiator and a second-order bandpass filter. Transmission zero is induced by the coupled line resonator, but the antenna size is 73 mm $\times$ 50 mm. In [5], based on a composite right-/left-handed (CRLH) resonator and a defected ground structure, a compact filtering antenna with two poles in the passband and two radiation zeros at the band edges is presented. An octagonal patch acts as a radiator as well as the last stage of the filter. The proposed design induces a little extra circuit area. Two microstrip square open-loop resonators can be used in the design of a filtering antenna [6], and shorting pins can also be used in the design of a filtering antenna [7]. In [8], a compact two-pole filtering antenna consisting of a fan-shaped patch antenna and defected ground structure is presented. The first step is the design of a two-pole Butterworth bandpass filter. Then, through substituting the second port and resonator with the fan-shaped antenna, the filtering antenna is designed. Several filtering antennas based on the structure of filter have been proposed in recent years [16–20].

In this letter, a new compact filtering antenna using a dumbbell-shaped resonator for a modern wireless communication system is presented. Based on the synthesis approach, a Γ-shaped antenna, a
coupled line and a dumbbell-shaped resonator are integrated to be a filtering antenna. The filtering antenna has a small size of $0.33\lambda_0 \times 0.17\lambda_0$ ($\lambda_0$ is the free-space wavelength at 2.45 GHz). The planar structure of the antenna is easy to design and integrate with wireless communications systems. It has better skirt selectivity than an ordinary $\Gamma$ shaped-patch antenna. Both simulated and measured results indicate that the characteristic of filtering based on dumbbell-shaped is achieved.

2. ANALYSIS OF DUMBELL-SHAPED RESONATOR

In this section, the properties of a dumbbell-shaped resonator are analyzed. As plotted in Figure 1, the basic of stepped impedance resonator consists of two lines of different characteristic impedances $Z_1$ and $Z_2$ and electrical lengths $\theta_1$ and $\theta_2$. Since the structure of resonator is symmetrical, the resonance conditions can be obtained from cell 1. The impedance of the resonator can be calculated as

$$Z_{in} = jZ_2 \frac{Z_1 \tan \theta_1 + Z_2 \tan \theta_2}{Z_2 - Z_1 \tan \theta_1 \tan \theta_2}$$  \hspace{1cm} (1)$$

when $1/Z_{in}$ is equal to zero, the resonance appears according to above equation. So, the following expression can be obtained

$$R_1 = \frac{Z_2}{Z_1} = \tan \theta_1 \tan \theta_2$$  \hspace{1cm} (2)$$

where $R_1$ represents the impedance ratio. Based on the expressions, it can be concluded that the resonance conditions are determined by $R_1$, $\theta_1$, and $\theta_2$.

Figure 2 plots the transformation process to design a dumbbell-shaped resonator. Due to its folded shape, the size of the structure gets reduced. Owing to the existence of via hole, magnetic coupling plays a role on the short stub loaded resonator.

3. DESIGN OF FILTERING ANTENNA

Based on above analysis, the bandpass structure can be designed through coupling the resonator. The configuration is shown in Figure 3(a). The lengths $l_1$ and $l_2$ are 4.1 mm and 0.4 mm. As plotted in Figure 3(b), the simulated curve of $S$-parameter is given from 1 GHz to 4 GHz. It points out that transmission zeros are induced.

In order to further study the characteristics of the resonator, parametric analyses of $l_1$ and $l_2$ are implemented. Figure 4(a) shows the effect of $l_1$ on $S$-parameter. With the increment of $l_1$, the transmission pole shifts to the lower frequency band.

Then, Figure 4(b) depicts the variation of the frequency response of the $S$-parameter with $l_2$. It points out that the length of $l_2$ affects the extent of coupling.

As depicted in Figure 5, the proposed filtering antenna is constructed by integrating the dumbbell-shaped resonator, a coupled line and a $\Gamma$-shaped antenna. Since the $\Gamma$-shaped antenna is a monopole antenna, it has an $RLC$ equivalent circuit as depicted in Figure 6(b) [4]. In an equivalent circuit, $L_a$ and $C_a$ represent the equivalent inductance and capacitance, respectively, and $R_a$ represents the antenna...
Figure 3. (a) The resonator design and (b) the $S$-parameter result.

Figure 4. (a) Variation of the frequency response of the $S$-parameter with $l_1$ and (b) $l_2$.

Table 1. Dimensions of the filtering antenna.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Size (mm)</th>
<th>Dimension</th>
<th>Size (mm)</th>
<th>Dimension</th>
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radiation resistance. Through integrating the equivalent circuit of the dumbbell-shaped resonator and \( \Gamma \)-shaped antenna, the filtering antenna can be represented by the circuit depicted in Figure 7.

The dimensions of the structure are shown in Table 1. Owing to the dumbbell shape, the antenna size gets reduced, and the planar structure is easy to fabricate.
4. SIMULATED AND MEASURED RESULTS

To validate the characteristic of filtering, the proposed antenna is fabricated and measured. It is fabricated on a 1 mm-thick F4B substrate with a relative dielectric constant of 2.65 and loss tangent of 0.003. Figure 8 depicts a photograph of the fabricated filtering antenna. The simulated and measured reflection coefficients of the filtering antenna are plotted in Figure 9. Here, Ansoft HFSS is used for simulation, and a vector network analyzer is used for measurement. The simulated/measured reflection coefficient is $-30\,\text{dB} / -23\,\text{dB}$ at 2.45 GHz. The measured $-10\,\text{dB}$ bandwidth is 6.7%. Compared with the ordinary Γ-shaped antenna, the filtering antenna has higher suppression.

The measured and simulated radiation patterns at 2.45 GHz in the $E$-plane and $H$-plane are presented in Figure 10. It is noticed that the radiation pattern in the $H$-plane is nearly omnidirectional. Measured results agree well with the simulated ones.

Figure 11 depicts the total gain of the filtering antenna. The total gain is flat in the passband from 2.4 to 2.5 GHz. From above results, it can be concluded that without suffering much from the need of extra area, the proposed dumbbell-shaped resonator and ordinary Γ-shaped antenna can be integrated to be a filtering antenna.

The operating mechanism of filtering antenna can be explained by the current distributions. As plotted in Figure 12, the surface current distributions at 2, 2.45, 3 GHz are given respectively. It can be noticed that a large surface current density is distributed on the whole dumbbell-shaped resonator and Γ-shaped antenna at 2.45 GHz, while it is distributed on part of the resonator at 2 and 3 GHz.
Figure 8. Photograph of the filtering antenna.

Figure 9. Reflection coefficient of the filtering antenna and ordinary patch antenna.

Figure 10. Simulated and measured radiation patterns of filtering antenna at 2.45 GHz. (a) $E$-plane. (b) $H$-plane.

Table 2. Comparison with other realizations.

<table>
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<th>References</th>
<th>$f_0$ (GHz)</th>
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<td>4</td>
<td>2.45</td>
<td>$73 \times 50$</td>
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The results indicate that the dumbbell-shaped resonator plays a leading role for the characteristic of filtering.

As shown in Table 2, the proposed design is compared with some presented realizations in the open literature. Owing to the insert of folded shape resonator, the proposed design induces a little extra circuit area.
Figure 11. Total gain of the filtering antenna.

Figure 12. Surface current distributions at (a) 2 GHz, (b) 2.45 GHz, (c) 3 GHz.

5. CONCLUSION

A new compact filtering antenna based on a dumbbell-shaped resonator is proposed. A coupled line is used to integrate the Γ-shaped and resonator. The proposed filtering antenna provides better selectivity within the passband. The measured results agree with the simulated ones. They also demonstrate that the integration has little impact on radiating functions. The total gain is flat in the passband from 2.4 to 2.5 GHz with the gain about 1.35 dBi. It has a simpler structure and more compact size. The proposed filtering antenna is suitable for modern wireless communications systems.

REFERENCES


