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 $0.33\lambda_0 \times 0.17\lambda_0$ (λ_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 ×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 $0.33\lambda_0 \times 0.17\lambda_0$ (λ_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 Γ shaped-patch antenna. Both simulated and measured results indicate that the characteristic of filtering based on dumbbell-shaped is achieved.

2. ANALYSIS OF DUMBBELL-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 θ_1 and θ_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

$$Z_{in} = jZ_2\frac{Z_1\tan\theta_1 + Z_2\tan\theta_2}{Z_2 - Z1\tan\theta_1\tan\theta_2} \tag{1}$$

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

$$R_1 = \frac{Z_2}{Z_1} = \tan\theta_1\tan\theta_2 \tag{2}$$

where R_1 represents the impedance ratio. Based on the expressions, it can be concluded that the resonance conditions are determined by R_1, θ_1 and θ_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.
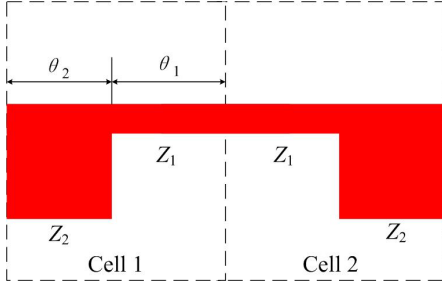

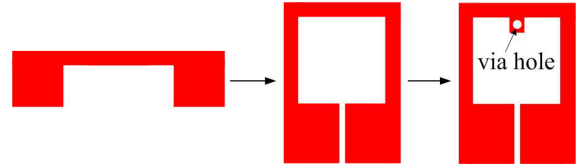**Figure 1.** Basic structure of stepped impedance resonator.

Figure 2. The design scheme of dumbbell-shaped 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 Γ-shaped antenna. Since the Γ-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
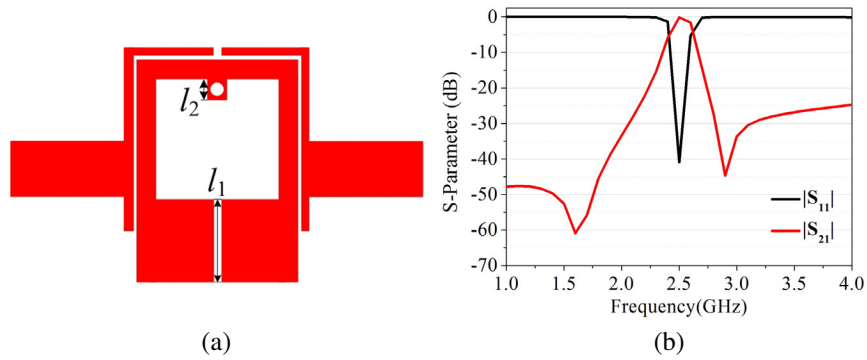
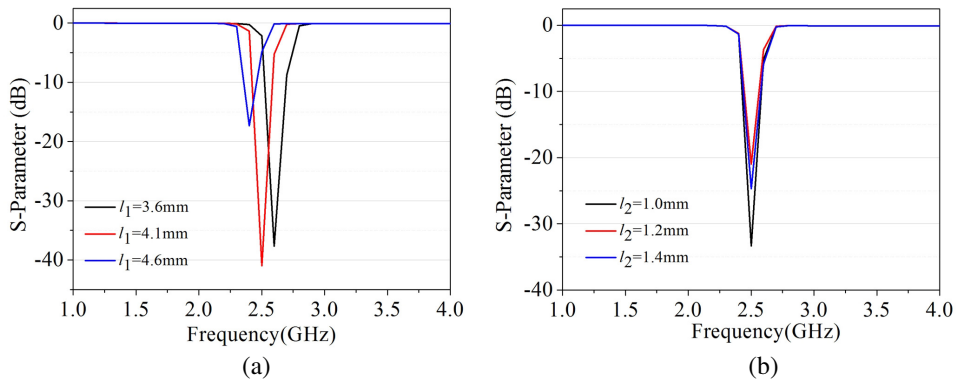**Figure 3.** (a) The resonator design and (b) the S-parameter result.

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.

Dimension	Size (mm)	Dimension	Size (mm)	Dimension	Size (mm)
L_1	3.7	D	0.2	d_3	0.4
L_2	15.3	W_1	1.9	d_4	1
L_3	12.1	W_2	1.4	d_5	1
L_4	5.9	W_3	1	L	42
L_5	4.1	W_4	3.8	W	22
L_6	4.6	W_5	0.4		
L_7	10.4	d_1	0.1		
L_8	18.5	d_2	0.4		

radiation resistance. Through integrating the equivalent circuit of the dumbbell-shaped resonator and Γ-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.
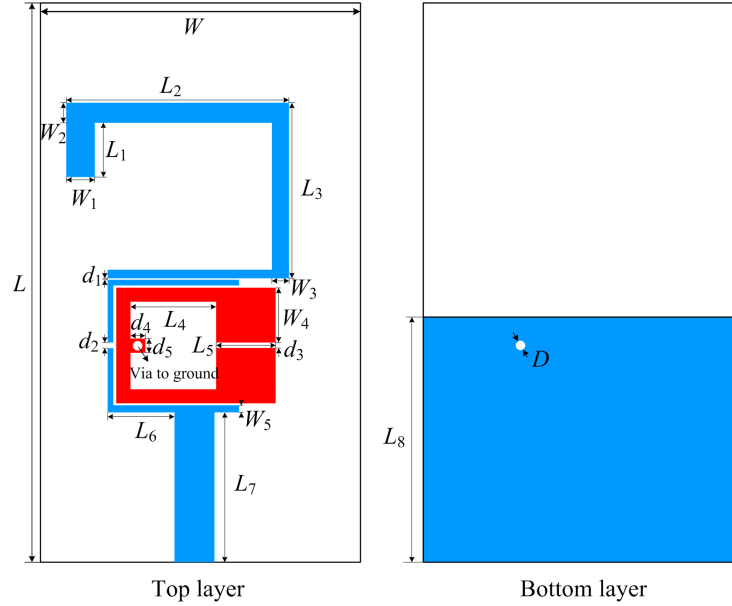
Figure 5. The top and bottom views of the proposed filtering antenna.
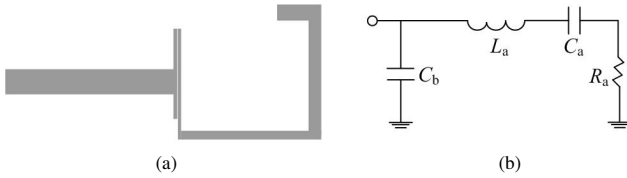

Figure 6. (a) The geometry of the Γ-shaped antenna. (b) The equivalent circuit of the Γ-shaped antenna.
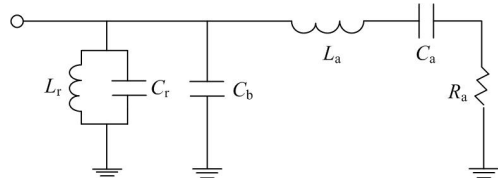
Figure 7. The equivalent circuit of the filtering antenna.

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 dB/-23.8 dB at 2.45 GHz. The measured -10 dB bandwidths 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.
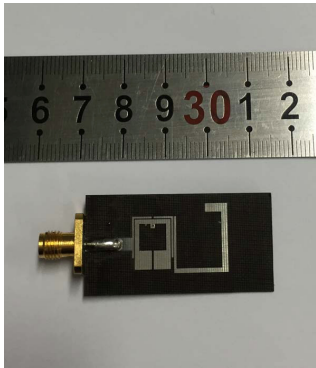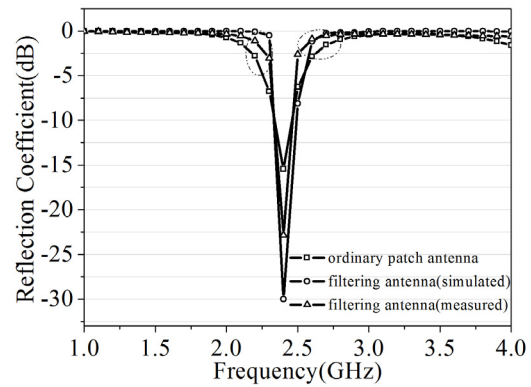
Figure 8. Photograph of the filtering antenna.

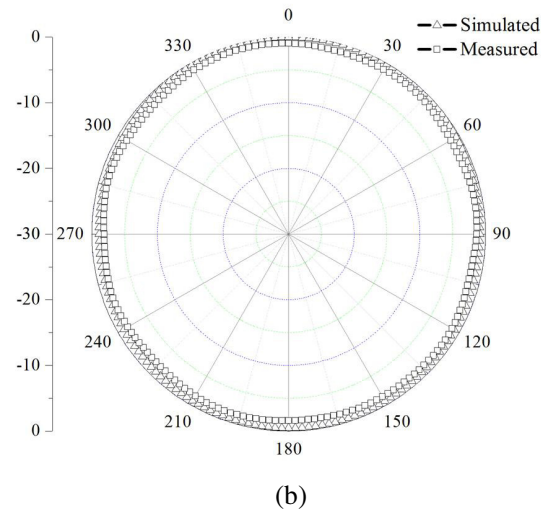**Figure 9.** Reflection coefficient of the filtering antenna and ordinary patch antenna.
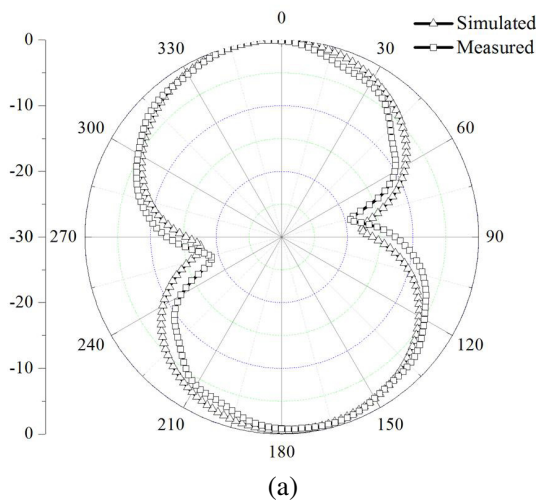

(a)

(b)

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.

References	f_0 (GHz)	size (mm^2)
[4]	2.45	73×50
[6]	2.45	73.5×50
[8]	2.40	37.5×31.6
This work	2.45	42×22

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.
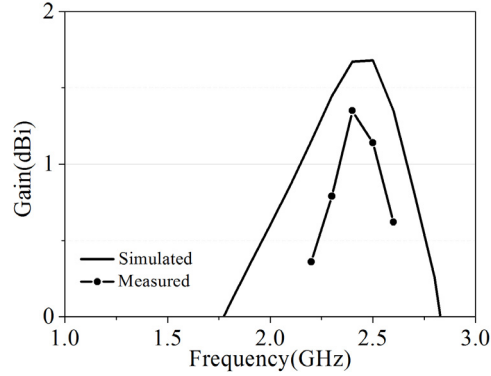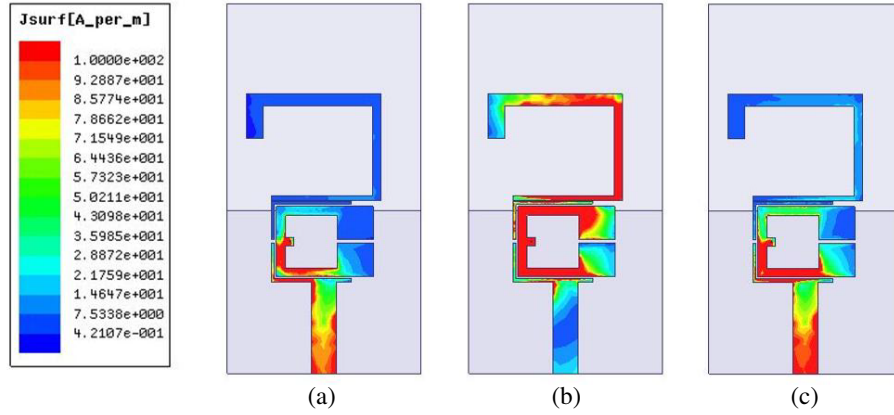
Figure 11. Total gain of the filtering antenna.

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

1. Wang, Z.-Y. and C.-P. Zhang, "A planar UWB antenna with triple-notched bands," *Progress In Electromagnetics Research Letters*, Vol. 52, 99–104, 2015.
2. Ding, C., J. Li, F. Wei, and X. Shi, "Compact bandpass filter based on parallel-coupled lines and quasi-lumped structure," *Frequenz*, Vol. 70, 11–15, 2016.
3. Wu, C.-M. and Y.-H. Liu, "An ultra-wideband twin-patch monopole antenna with band-rejection characteristic," *Progress In Electromagnetics Research Letters*, Vol. 53, 77–82, 2015.
4. Chuang, C.-T. and S.-J. Chung, "A compact printed filtering antenna using a ground-intruded coupled line resonator," *IEEE Transactions on Antennnas and Propagation*, Vol. 59, No. 10, 2011.

5. Chen, L. and Y.-L. Luo, "Compact filtering antenna using CRLH resonator and defected ground structure," *Electronics Letters*, Vol. 50, No. 21, 1496–1498, 2014.

6. Wu, W.-J., Y.-Z. Yin, S.-L. Zuo, Z.-Y. Zhang, and J.-J. Xie, "A new compact filter-antenna for modern wireless communication systems," *IEEE Antennnas and Wireless Propagation Letters*, Vol. 10, 1131–1134, 2011.

7. Wong, S. W., T. G. Huang, C. X. Mao, Z. N. Chen, and Q. X. Chu, "Planar filtering ultra-wideband (UWB) antenna with shorting pins," *IEEE Transactions on Antennas and Propagation*, Vol. 61, No. 2, 948–952, 2013.

8. Chen, X., F. Zhao, L. Yan, and W. Zhang, "A compact filtering antenna with flat gain response within the passband," *IEEE Antennnas and Wireless Propagation Letters*, Vol. 12, 857–860, 2013.

9. Hsieh, C.-Y., C.-H. Wu, and T.-G. Ma, "A compact dual-band filtering patch antennausing step impedance resonators," *IEEE Antennnas and Wireless Propagation Letters*, Vol. 14, 1056–1059, 2015.

10. Wu, P.-C., L. Chen, and Y.-L. Luo, "Miniaturised wideband filtering antenna by employing CRLH-TL and simplified feeding structure," *Electronics Letters*, Vol. 51, No. 7, 548–550, 2015.

11. Duan, W., X. Y. Zhang, Y.-M. Pan, J.-X. Xu, and Q. Xue, "Dual-polarized filtering antenna with high selectivity and low cross polarization," *IEEE Transactions on Antennas and Propagation*, Vol. 64, No. 10, 4188–4196, 2016.

12. Lin, C.-K. and S.-J. Chung, "A compact filtering microstrip antenna with quasi-elliptic broadside antenna gain response," *IEEE Antennas and Wireless Propagation Letters*, Vol. 10, 381–384, 2011.

13. Hsieh, C.-Y., C.-H. Wu, and T.-G. Ma, "A compact dual-band filtering patch antenna using step impedance resonators," *IEEE Antennas and Wireless Propagation Letters*, Vol. 14, 1056–1059, 2015.

14. Jiang, Z. H. and D. H. Werner, "A compact, wideband circularly polarized co-designed filtering antenna and its application for wearable devices with low SAR," *IEEE Transactions on Antennas and Propagation*, Vol. 63, No. 9, 3808–3818, 2015.

15. Zhang, X. Y., W. Duan, and Y.-M. Pan, "High-gain filtering patch antenna without extra circuit," *IEEE Transactions on Antennas and Propagation*, Vol. 63, No. 12, 5883–5888, 2015.

16. Koley, S. and D. Mitra, "A planar microstrip-fed tri-band filtering antenna for WLAN/WiMAX applications," *Microwave and Optical Technology Letters*, Vol. 57, No. 1, 233–237, 2015.

17. Soltanpour, M. and M. M. Fakharian, "Compact filtering slot antenna with frequency agility for Wi-Fi/LTE mobile applications," *Electronics Letters*, Vol. 52, No. 7, 491–492, 2016.

18. Mandal, M. K., Z. N. Chen, and X. Qing, "Compact ultra-wideband filtering antennas on low temperature co-fired ceramic substrate," *Asia Pacific Microwave Conference*, 2009.

19. Zuo, J. H., X. W. Chen, G. R. Han, L. Li, and W. M. Zhang, "An integrated approach to RF antenna-filter co-design," *IEEE Antennas and Wireless Propagation Letters*, Vol. 8, 141–144, 2009.

20. Fakharian, M. M., P. Rezaei, A. A. Orouji, and M. Soltanpur, "A wideband and reconfigurable filtering slot antenna,," *IEEE Antennas and Wireless Propagation Letters*, Vol. 15, 2016.