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A Dual-Band Two Order Filtering Antenna

Jingli Guo, Haisheng Liu*, Bin Chen, and Baohua Sun

Abstract—A dual-band two order filtering antenna is designed to cover both the GSM900 and GSM1900 bands. The resonator of the two order filter contains a half wavelength open-loop resonator and a T-shaped open stub. The antenna is composed of two parts. One is a printed monopole which covers lower frequency band, and the other is a strip with slot protruded from the ground plane, which covers higher frequency band. By substituting the antenna for the last resonator of the filter, the filtering antenna owns not only a good radiation function but also a good character of filter at the two working frequency bands.

1. INTRODUCTION

With the development of wireless communications, the requirements for the electronic devices of wireless system become higher and higher, which include multi-function, miniaturization and multi-band. As two components located in the front end of a system, both the filter and antenna have attracted much attention of researchers in the past decades. In [1], a bandpass filter was embedded in the front of a patch antenna in place of the microstrip line, which saved the space to some extent. But this co-design method needs to consider impedance mismatch, which will increase the overall size of the whole device when the impedance matching part is introduced.

Recently, many researchers have studied the filter synthesis process for filters and antennas. In these designs, the last resonator or the load impedance of the bandpass filter is substituted by an antenna, and it is modeled using a series or parallel RLC equivalent circuit. In [2], an inverted-L antenna and the parallel coupled line are used to illustrate the synthesis of a bandpass filtering antenna, but the overall size is still big due to the parallel half-wavelength microstrip lines. In [3], two microstrip square open-loop resonators, a coupled line and a Γ-shaped antenna are integrated into a filtering antenna. In [4], a full-wavelength circular open-loop resonator and a fan-shaped patch antenna with DGS are designed together to form the filtering antenna. In [5], a rectangular patch antenna integrated with four square open-loop resonators is designed to verify the filtering antenna function. A filtering microstrip antenna working at 2 GHz is proposed using filter synthesis approach [6]. Another filtering antenna working at 2 GHz using dual-mode resonator is presented in [7]. The aforementioned filtering antennas all focus on a single frequency band. Nowadays, dual-band or multiband devices are needed in many communication systems. To design a filtering antenna possessing dual-band function is very urgent.

In this letter, a new compact two-pole dual-band filtering antenna is presented. First, a two-pole dual-band filter is designed using two open loop resonators with T-shaped open stubs. Then, the second port and second resonator of the filter are replaced by a corresponding antenna to form the dual-band filtering antenna. By adjusting the coupling configuration, the filtering antenna is designed, fabricated and measured. The results show that the designed filtering antenna has a similar reflection property to that of a filter.

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* Corresponding author: Haisheng Liu (liu001haisheng@163.com).
The authors are with the National Laboratory of Antennas and Microwave Technology, Xidian University, Xi'an, Shaanxi 710071, People's Republic of China.

2. DESIGN OF A FILTER

A two-pole dual-band filter based on the idea presented in [8] is designed first. As shown in Fig. 1, the filter comprises two resonators, and each resonator is composed of a half wavelength open-loop resonator and a T-shaped open stub. The stub here is put outside the open loop for the facility of antenna coupling. Besides that, the width of each arm of the resonator is different to constitute a stepped impedance resonator [9]. The filter is designed to operate at 900 MHz and 1900 MHz on a PCB with a relative permittivity of 2.65. The dimensions of filter are $a = 24.5\,\mathrm{mm}$, $b = 23\,\mathrm{mm}$, $W_1 = 4.5\,\mathrm{mm}$, $W_2 = 0.6\,\mathrm{mm}$, $W_3 = 1\,\mathrm{mm}$, $W_4 = 0.7\,\mathrm{mm}$, $W_5 = 1.5\,\mathrm{mm}$, $W_6 = 0.2\,\mathrm{mm}$, $S = 0.2\,\mathrm{mm}$, $d = 0.9\,\mathrm{mm}$, $L_1 = 6.8\,\mathrm{mm}$, $L_2 = 5.8\,\mathrm{mm}$, $L_3 = 7\,\mathrm{mm}$, $L_4 = 6.9\,\mathrm{mm}$, $L_5 = 3.5\,\mathrm{mm}$, $L_6 = 5\,\mathrm{mm}$ and $g = 0.6\,\mathrm{mm}$.

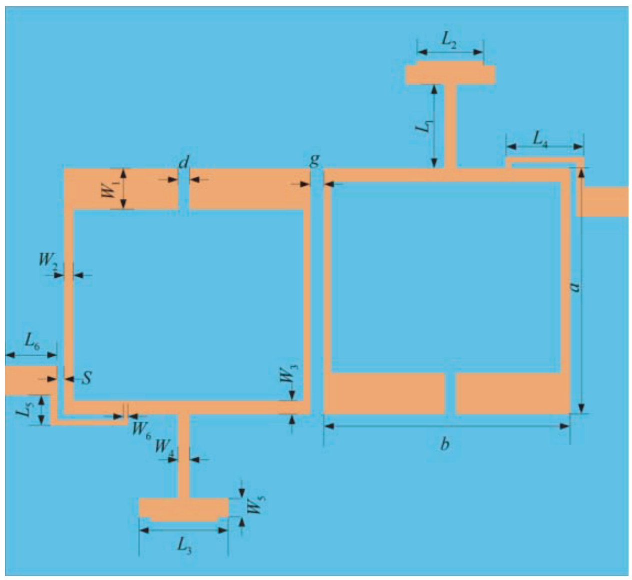


Figure 1. Designed bandpass filter.

The current on the filter at 900 MHz is given in Fig. 2(a). It is obvious that the current concentrates mainly on the three narrow arms of each resonator, and there is a little current on the open stubs. Fig. 2(b) shows the current distribution at 1900 MHz. It can be seen that the current flows into not only the three arms, but also the open stubs. In short, the two current paths provide two resonant frequencies.

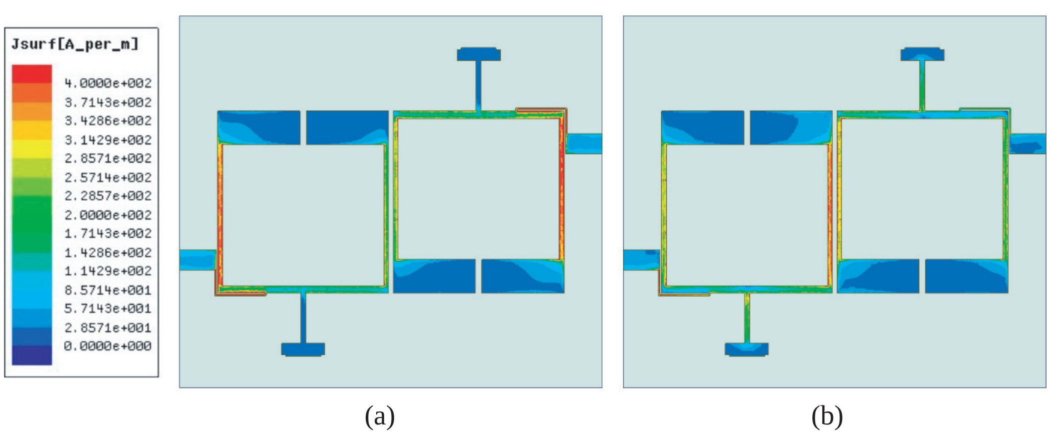


Figure 2. Surface current distributions of the proposed filter. (a) 900 MHz. (b) 1900 MHz.

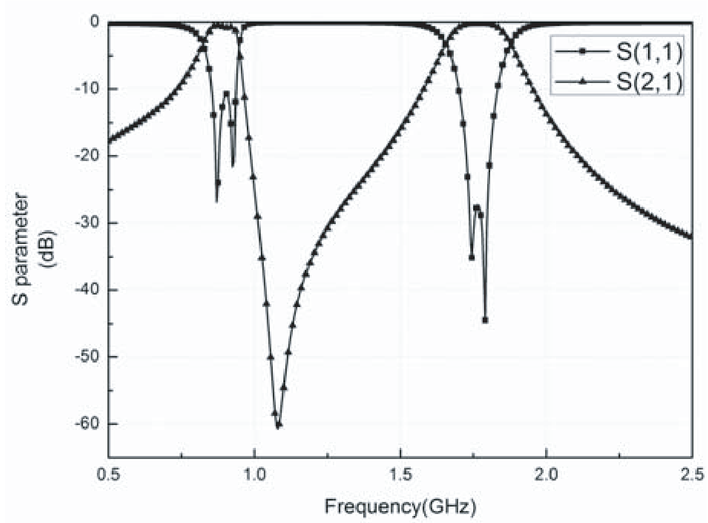


Figure 3. Simulated S-parameter of the proposed filter.

Figure 3 plots the simulated S-parameters of this filter. Obviously, the filter has a dual-band character, which can cover 847–931 MHz and 1694–1833 MHz. The insertion losses are less than 1 dB in the both working bands. In addition, a transmission zero appears at the right of the lower frequency band, which is caused by the coupling of the source and load.

3. DESIGN OF AN ANTENNA

In order to obtain a filtering antenna, an independent antenna with appropriate properties is necessary [10]. Here, a dual-band antenna structure including a printed monopole and a strip protruded from the ground plane is designed. The aforementioned two structures resonate at lower and higher frequency bands, respectively. The printed monopole is driven by a 50 Ω feed line, while the grounded strip part is excited by the changing of the current on the ground. Considering the coupling strength between the two antenna parts, the distance between them needs to be optimized thoroughly.

Figure 4 shows the structure of the proposed antenna. Similar to the filter designed before, the antenna is built on a PCB with a relative permittivity of 2.65 too. The length of feed line is equal to the size of one resonator plus the folded feed line in Fig. 1. The ground antenna is slotted, and there

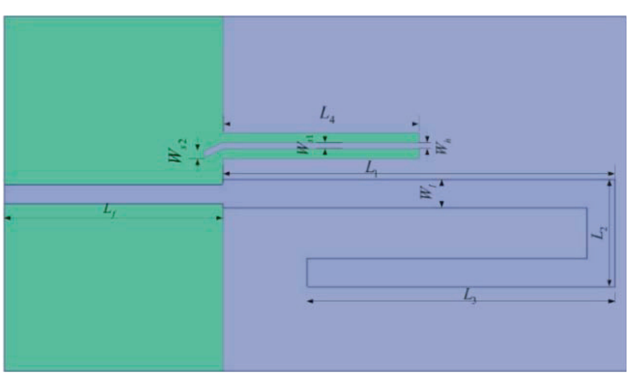


Figure 4. Designed independent antenna.

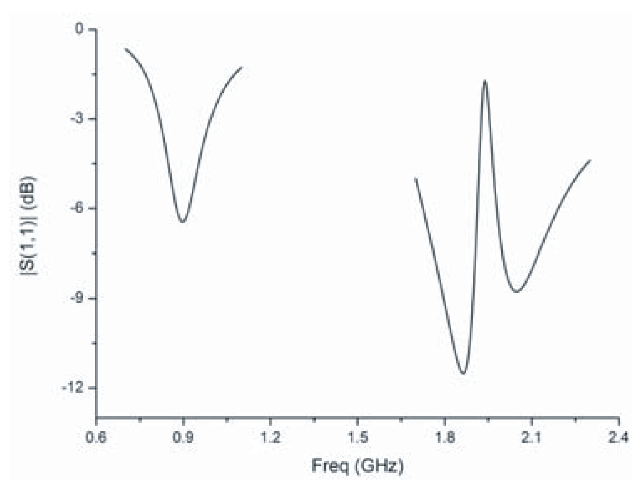


Figure 5. Reflection coefficients of the antenna.

also exists an oblique slot in the ground. These two slots are beneficial to the coupling and impedance matching. The antenna size is $W_1 = 4\,\text{mm}$, $W_h = 3.5\,\text{mm}$, $W_{s1} = 0.8\,\text{mm}$, $W_{s2} = 1\,\text{mm}$, $L_f = 31.3\,\text{mm}$, $L_1 = 56\,\text{mm}$, $L_2 = 15\,\text{mm}$, $L_3 = 44\,\text{mm}$ and $L_4 = 26.2\,\text{mm}$.

Noted that only the idea of antenna design is verified here, so the impedance matching is not taken into attention, which leads to a not very good S_{11} of the antenna in Fig. 5. It will be adjusted with the filter together in the design later. Except the lower resonant frequency 900 MHz, the antenna produces the other two resonances from 1800 MHz to 2200 MHz, which are due to the higher frequency antenna and second harmonic of the lower frequency, respectively. With the filter added in the following section, it will be seen that one resonance in higher frequency band will disappear.

4. SYNTHESIS DESIGN OF THE FILTERING ANTENNA

Figure 6 shows the layout of the two order filtering antenna, and the resonator and antenna are connected by three coupling lines (labeled 1, 2 and 3). By changing the distance between coupling lines and the first resonator, the energy transferred to antenna can be adjusted. Taking the electrical properties through simulations by HFSS and fabrication precision into consideration, the optimized size of them is selected as follows, $L_1 = 18.4\,\text{mm}$, $L_2 = 13\,\text{mm}$, $L_3 = 6.4\,\text{mm}$, $W_1 = 2\,\text{mm}$, $W_2 = 2.4\,\text{mm}$, $W_3 = 2.4\,\text{mm}$, $S_1 = 0.12\,\text{mm}$, $S_2 = 0.12\,\text{mm}$ and $S_3 = 0.25\,\text{mm}$, in which L is the length of the coupling line, W the width of the coupling line, and S the distance between the coupling line and the filter. Compared with the dimension given in the separated filter and antenna, there are some variations of the parameters for obtaining good performance ($W_2 = 0.92\,\text{mm}$ and $L_6 = 6.2\,\text{mm}$).

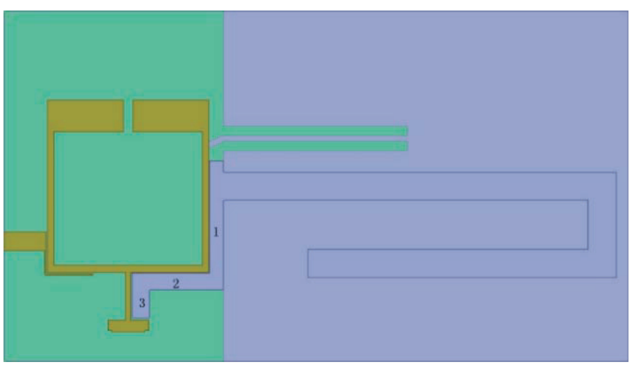


Figure 6. Structure of the designed filtering antenna.

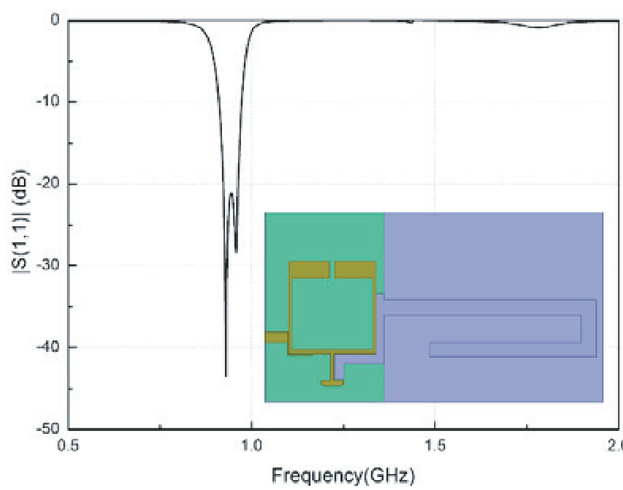


Figure 7. S-parameter of the printed monopole filtering antenna.

To observe the working principle of the integrated antenna thoroughly, the higher frequency antenna in Fig. 6 is removed, only the filter, coupling line and lower frequency antenna are kept, as shown in Fig. 7. The reflection coefficients of the filter antenna are simulated through HFSS.

As illustrated in Fig. 7, a good resonance at 900 MHz is produced, and a double ripple emerges in this frequency band, which is in accordance with the design concept of the filter antenna. Besides that, the second harmonic resonance at 1800 MHz vanishes compared with Fig. 5. The fact leading to this phenomenon can be observed from the surface current flow on this filter antenna. As presented in Fig. 8, there is almost no current distribution on the antenna when it is working at 1.9 GHz. The current mainly concentrates on the narrow side of the filter, and only a little is distributed in the parallel coupled line. So it can be concluded that the second harmonic of the printed monopole is filtered by the filter.

Then the printed monopole and its coupling line are removed, just the ground antenna for higher frequency band is preserved. The configuration is given in Fig. 9. It is clear that the current flows to

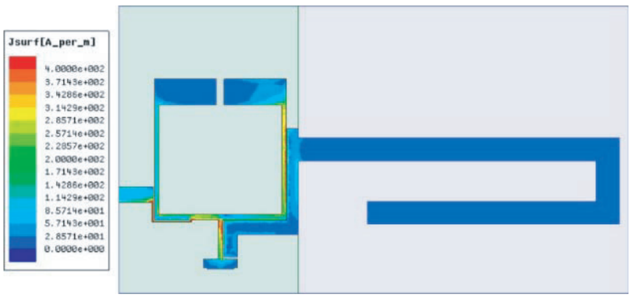


Figure 8. Current distribution of the proposed antenna (Top view).

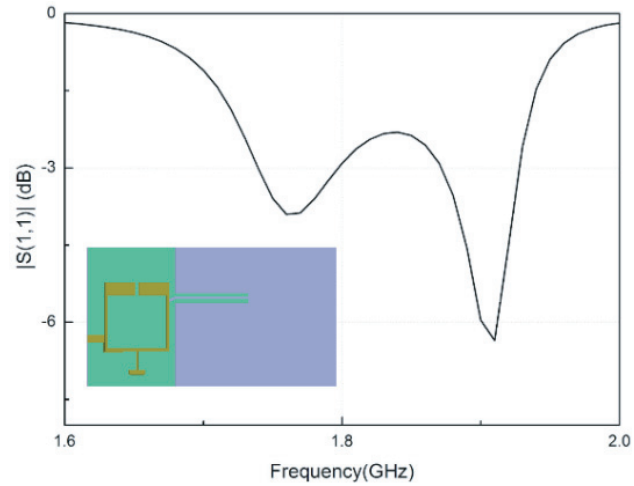


Figure 9. S_{11} of advanced ground antenna filtering antenna.

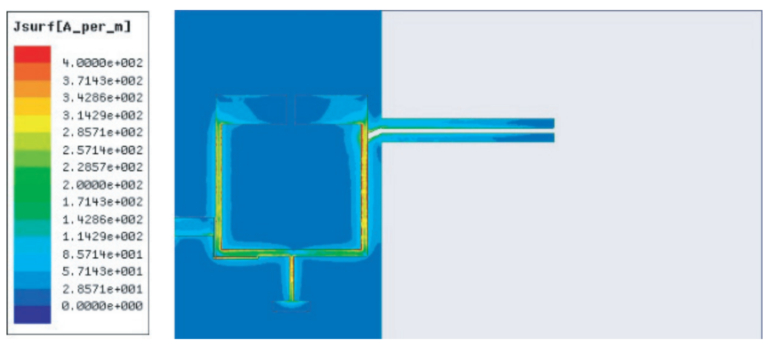
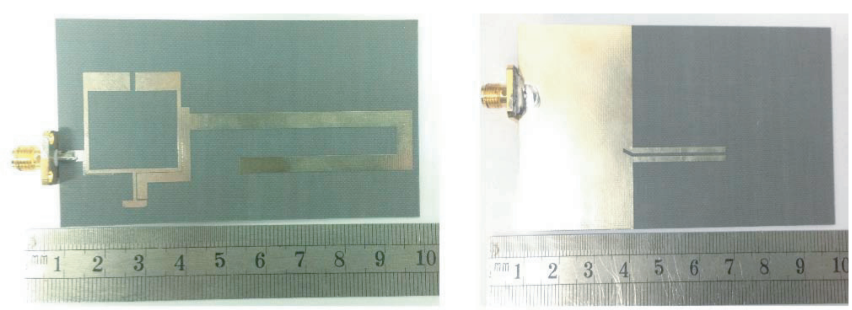


Figure 10. Current distribution of proposed antenna (Top view).



(a) (b)

Figure 11. Photograph of the proposed filtering antenna. (a) Top view. (b) Bottom view.

the ground plane as shown in Fig. 10. It can be seen from Fig. 9 that two ripples are produced too in the frequency near 1.9 GHz. The resonant depth is not enough here due to the size selected, but it can be improved by coupling with the printed monopole and the parallel coupling line because the size is optimized for that case, which will be illustrated in the following discussion.

At last, the two independent antennas are integrated together. The filtering antenna is fabricated on a 1-mm-thick substrate ($\varepsilon_r = 2.65$), and its photographs are shown in Fig. 11.

The measured S_{11} of the filtering antenna is compared with the simulated one in Fig. 12. As shown

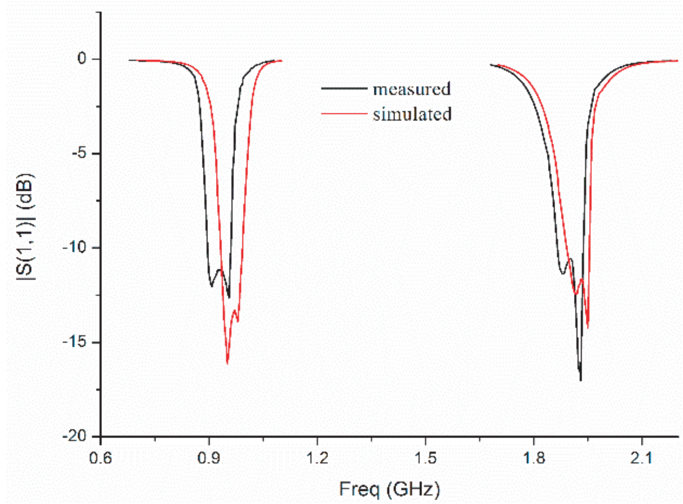


Figure 12. Simulated and measured S_{11} of the proposed filtering antenna.

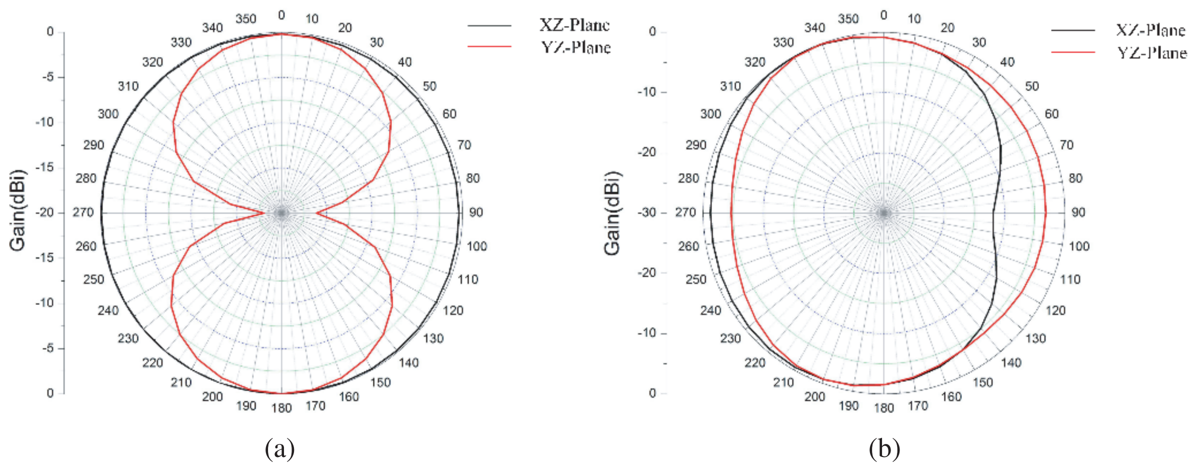


Figure 13. Simulated radiation patterns of the proposed filtering antenna. (a) 900 MHz. (b) 1900 MHz.

in Fig. 12, S_{11} of the designed dual-band two order filtering antenna is less than -10 dB in the bands of 0.93–0.99 GHz and 1.89–1.96 GHz. Furthermore, the amplitude frequency responses of the filtering antenna are similar to those of a band-pass filter. There is a steep curve at the low frequency band, which shows that the band suppression is good. In addition, double ripples are produced in both of the bands. The deviation of the measured results from simulated one is because of the fabrication error.

The simulated normalized radiation patterns of the antenna are shown in Fig. 13. It can be observed that the antenna has a similar radiation property to a monopole at 900 MHz. At 1.9 GHz, a nearly omnidirectional radiation is obtained, and the deformation is due to the coupling of the monopole and the ground antenna. The results show that the antenna can not only play a role of one order filter, but also radiate well when they are integrated with the filter.

5. CONCLUSION

In this letter, a compact dual-band filtering antenna is designed. The dual-band antenna structure includes a printed antenna and a strip protruded from ground, which acts as a radiator in the two frequency bands (0.93–0.99 GHz and 1.89–1.96 GHz) as well as the second resonator of the filter. The measured results show that the proposed filtering antenna presents a performance of a filter and antennas simultaneously.

REFERENCES

1. Panda, J. R., P. Kakumanu, and R. S. Kshetrimayum, "A wide-band monopole antenna in combination with a UWB microwave band-pass filter for application in UWB communication system," *IEEE India Conference*, 1–4, 2011.
2. Chuang, C. T. and S. J. Chung, "Synthesis and design of a new printed filtering antenna," *IEEE Transactions on Antennas & Propagation*, Vol. 59, No. 3, 1036–1042, 2011.
3. Wu, W. J., Y. Z. Yin, and S. L. Zuo, "A new compact filter-antenna for modern wireless communication systems," *IEEE Antennas & Wireless Propagation Letters*, Vol. 10, No. 4, 1131–1134, 2011.
4. Chen, X., F. Zhao, and L. Yan, "A compact filtering antenna with flat gain response within the passband," *IEEE Antennas & Wireless Propagation Letters*, Vol. 12, No. 4, 857–860, 2013.
5. Shang, X. and M. J. Lancaster, "Patch antenna with integrated bandpass filter," *Seminar on Passive Rf & Microwave Components*, 1–5, 2013.
6. Mansour, G., M. J. Lancaster, P. S. Hall, P. Gardner, and E. Nugoolcharoenlap, "Design of filtering microstrip antenna using filter synthesis approach," *Progress In Electromagnetics Research*, Vol. 145, 61–67, 2014.
7. Yao, Z. H. and D. Chen, "A novel filtering antenna using dual-mode resonator," *Progress In Electromagnetics Research Letters*, Vol. 58, 113–118, 2016.
8. Hong, J. S., H. Shaman, and Y. H. Chun, "Dual-mode microstrip open-loop resonators and filters," *IEEE Transactions on Microwave Theory & Techniques*, Vol. 55, No. 8, 1764–1770, 2007.
9. Makimoto, M. and S. Yamashita, "Bandpass filters using parallel coupled stripline stepped impedance resonators," *IEEE Transactions on Microwave Theory & Techniques*, Vol. 28, No. 12, 1413–1417, 1981.
10. Liu, X., Y. Li, and W. Yu, "A simple dual-band antenna using a meander line and a tapered rectangle patch for WLAN applications," *IEEE International Conference on Communication Problem-solving*, 2014.