Integrated Filtering-Antenna with Controllable Frequency Bandwidth

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***Abstract*— An integrated design of a band-pass filter and a patch antenna is proposed in this paper by using an aperture coupled structure. Traditionally, the microwave filter and antenna are designed separately using 50 Ohm interface and then connected by transmission lines, which lead to a large size and more loss. Here, the antenna and microwave filter are directly integrated without a 50 Ohm interface between them. Compared with the traditional cascade designing, the co-design of filter and antenna has a more compact size, simpler configuration, improved frequency selectivity and higher system efficiency. The frequency bandwidth also can be controlled by adjusting the dimension of the coupling aperture in the ground. The measured results agree very well with the simulations, showing the filtering-antenna has good performance in impedance matching, radiation pattern and antenna gain.**

***Index Terms*—filtering-antenna, aperture, patch, bandwidth**

I. Introduction

The filter and the antenna are key components in wireless systems, such as satellites, mobile, base-stations and synthetic aperture radars. Historically, the different designing methods and basic theory between the filters and antennas lead to the division of "filter community" and "antenna community". Filters and antennas are designed separately and then cascaded into a system. The input ports are assumed to be ideal 50 Ohm interface in the designing of filter and antenna. However, this assumption are not accurate in practical filter and antenna designing, leading to deteriorated performance when one of components is not good enough.

Traditionally, the microwave filter and antenna are designed separately using 50 Ohm interface and then connected by transmission lines, which lead to a large size and more loss. Integrated design could significantly reduce the complexity of the system as the separate feeding/matching circuit are no longer needed [1]-[3]. Here, the feeding networks are replaced by filter. The antenna can be regarded as one resonators of the filter with radiating characteristics. In addition, the integration removes the inserted loss introduced by the interconnection between filter and antenna.

In a cascade communication system, the bandwidth is determined by the narrowest band of the subsystem. The integration of the filter in an antenna design could increase the selectivity of the antenna. In the case of a narrowband antenna,

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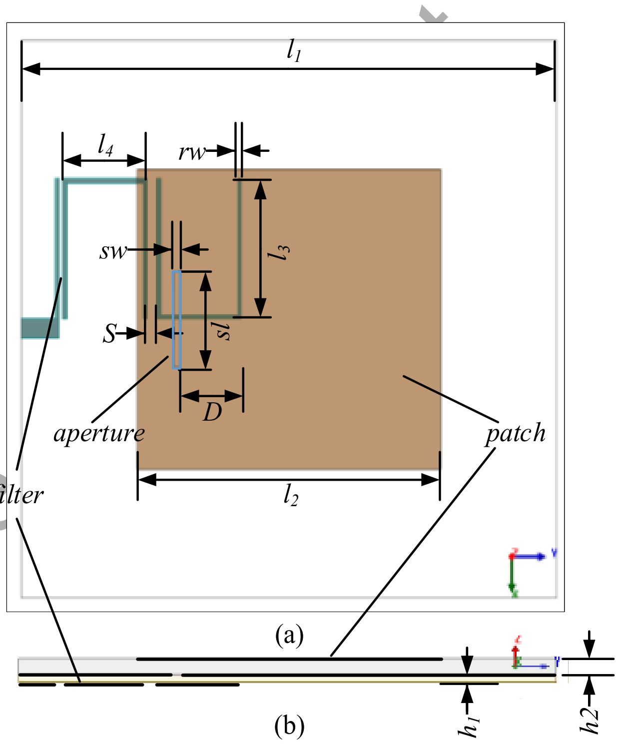


Fig. 1 The configuration of filtering-antenna: (a) top view, (b) side view

such as a patch antenna, the integration with a filter can increase the bandwidth [4] [5]. Filtering-antenna designing can also be used to eliminate the higher order harmonics [6] [7], and improve the antenna gain response [8] [9]. In [10], a third-order filtering antenna is proposed with good performance, however, the size is too large and not easy for integration.

In this paper, a filtering-antenna is proposed by integrating a second order band-pass filter with a microstrip patch antenna. The whole system is very simple and easy to fabricate. The filter and antenna are coupled by a rectangular aperture. This filtering-antenna is designed for narrowband communication system with a sharp transit from out-band to in-band at the both sides of the frequency band. Moreover, the bandwidth can be easily controlled by adjusting the dimension of the aperture and location of the feeding. The simulated and measured results match very well, which demonstrates the good performance of this filtering-antenna in terms of impedance

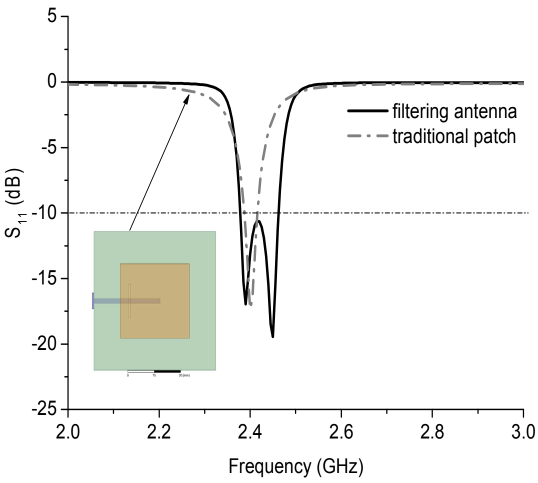


Fig. 2 The S_{11} of the filtering-antenna and a traditional patch antenna

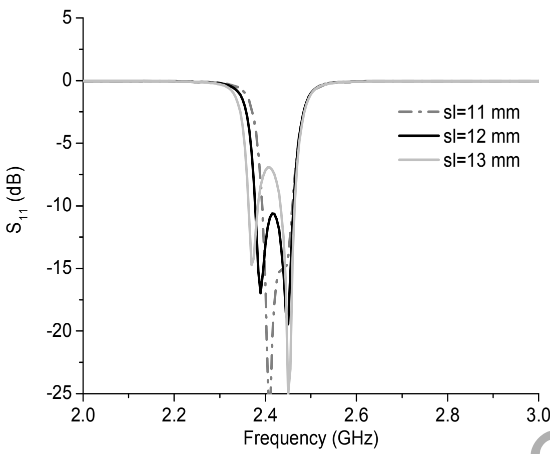


Fig.3 The S_{11} results versus the lengths of the aperture

matching, radiation pattern, antenna gains and cross-polarization (XPD).

II. FILTERING-ANTENNA DESIGN

Fig. 1 shows the geometry and configuration of the proposed filtering-antenna, which is consists of two hair-pin resonators on the bottom layer and a patch on the top layer. The resonators and patch share the same ground in the middle layer. The stacked configuration can not only make the design more compact and isolate the filter from the radiator, but also facilitate the integration with a back-end circuit. The patch on the top is fed through a rectangular aperture in the ground. The coupling strength between the resonator and the patch can be controlled by adjusting the dimension of the aperture and the location of the aperture. The resonators and patch are printed on the Rogers RT/duroid 5880 substrate with a dielectric constant of 2.2. The thickness of the lower substrate h_1=0.787 mm and the thickness of the upper substrate is h_2=1.575 mm.

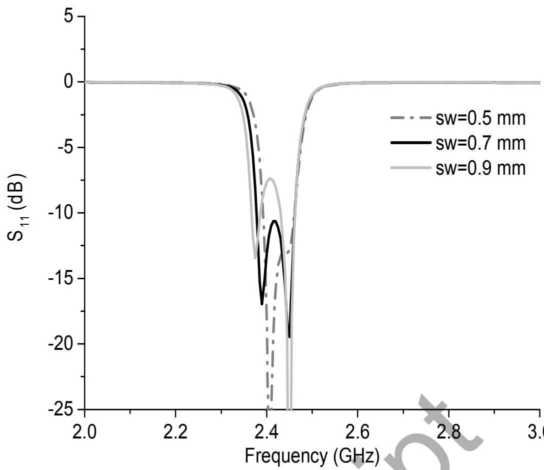


Fig.4 The S_{11} results versus the widths of the aperture

Table 1: Parameters of the filtering antenna: (MM)

l_1	l_2	l_3	l_4	S	D
35	39.6	17.6	10	1.3	7.9
sl	*sw*	*rw*	h_1	h_2	
12	0.7	0.4	0.787	1.575	

The simulation were performed using High Frequency Simulation Software (HFSS 15.0) and the optimized parameters are presented in Table 1.

The traditional patch antenna has only one resonant frequency, which results in a narrow operating bandwidth. When the patch is coupled with the resonator, the bandwidth of the filtering-antenna can be improved significantly. The simulated S_{11} of the proposed filtering antenna and a traditional patch antenna are presented in Fig. 2 for comparison. It is observed that the fractional bandwidth of the filtering-antenna is about 4.2%, which is about double of that of traditional patch antenna, since a new mode is introduced by the hairpin resonators. Additionally, filtering-antenna has a sharper transit at both sides of the band. The improved frequency selectivity can be used to suppress the interference from the adjacent frequency band. In this case, a separate band-pass filter is not necessary, so the volume and complexity of the system can be greatly reduced.

In this filtering-antenna design, the patch on the top layer is coupled with the second hair-pin resonator through a rectangular aperture. It is also known that the bandwidth of a band-pass filter is controlled by the coupling strength. The coupling strength is determined by the dimension of the aperture. As a consequence, the bandwidth of the filtering-antenna system can be easily controlled by tuning the dimension of the aperture. Fig. 3 shows the bandwidth of the filtering-antenna for different lengths of the aperture. The increase in length leads to stronger coupling and therefore, increases in bandwidth. The width of the aperture has a similar effect on the bandwidth, as is depicted in Fig. 4. A wider of the aperture can bring about a wider bandwidth.

It should be noted that the coupling location between the resonator and the aperture also has a significant influence on

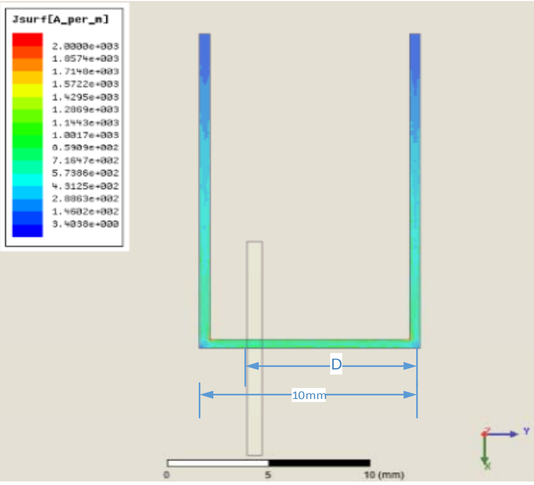


Fig. 5 The simulated current distribution at 2.4 GHz

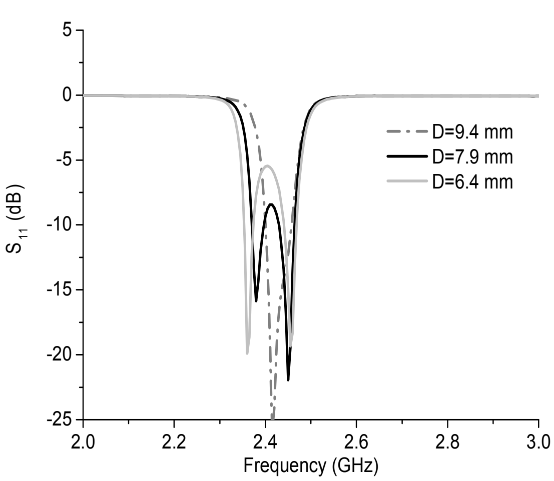
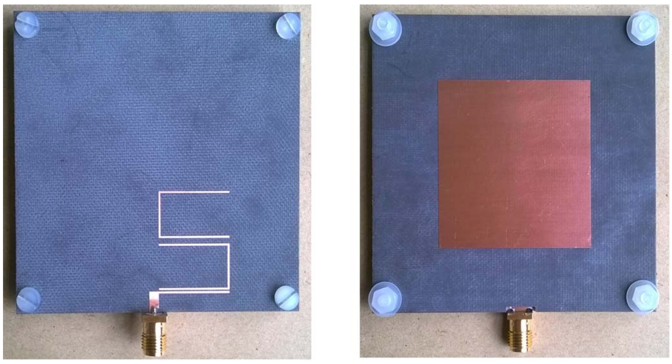


Fig. 6 The S_{11} results versus the locations of the aperture

the bandwidth of the filtering-antenna. Fig. 5 shows the current distribution of the U-shape resonator when it resonates at 2.4 GHz. It is observed that the current intensity decreases from the center to the end of the resonator, which is consistent with the intensity of the magnetic field. So, the coupling strength, as well as bandwidth of the filtering-antenna, can be controlled by adjusting the relative coupling location of the resonator and aperture. The influence of the coupling location on the S_{11} is shown in Fig. 6. It is observed that the bandwidth decreases when the coupling point shifts from center to sides of the resonator. This provides another degree of freedom to control the bandwidth of filter-antenna.

III. Results and Discussion

Fig. 7 shows the photograph of the bottom and top layer of the prototype filtering antenna. The simulated and measured S_{11} are shown in Fig. 8. It is observed that they match very well with each other with two reflection zeros at 2.35 and 2.45 GHz. The two reflection zeros in a narrow band improve the



(a) (b)

Fig. 7 The photograph of the filtering antenna: (a) bottom layer, (b) top layer

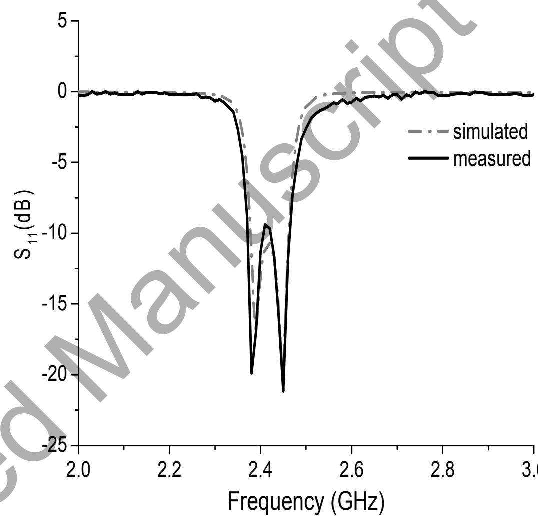
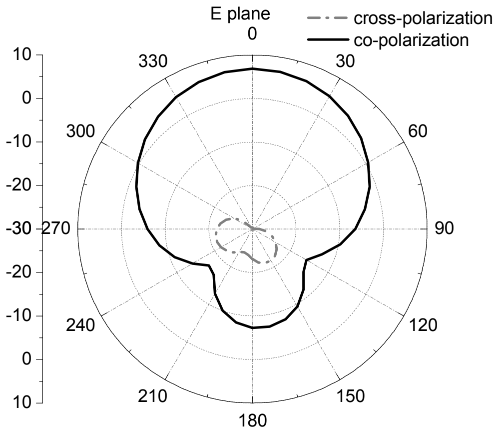


Fig. 8 The simulated and measured S_{11} of the proposed filtering antenna

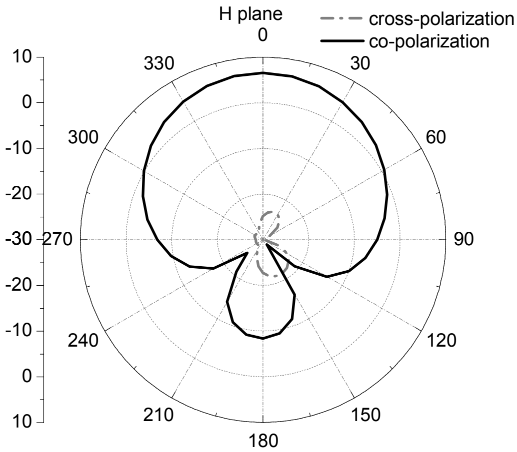
selectivity of the operating band, so that a good inhibition of frequency interference can be achieved. The minor difference between the simulated and measured results is caused by the influence of the measurement accuracy and fabrication error.

Fig. 9 shows the simulated co- and cross-polarization radiation pattern in E- and H-plane at 2.4 GHz, respectively. The antenna shows a good radiation performance with a maximum gain of 7 dBi. Due to the use of the aperture-coupled structure, the antenna has an excellent polarization performance with cross-polarization of over 35 dB.

Fig. 10 shows the simulated gain and realized gain of the filtering-antenna in comparison with the traditional patch from 2 to 3 GHz. It is observed from the curve of realized gain that the maximum gain (7 dBi) is at around 2.4 GHz, and which sharply decreases to below -20 dBi when the frequencies move from center frequency to both lower and higher frequencies. In the operating band, the realized gain is approximately equal to the gain, whereas the realized gain is much smaller out of the band. This discrepancy is attributed to the filtering performance of the filtering-antenna. Compared with the traditional patch, the filtering-antenna has a flatter gain response and better frequency selectivity, which demonstrate a good filtering performance is achieved.



(a)



(b)

Fig. 9 The simulated radiation pattern at 2.4 GHz: (a) E plane, (b) H plane

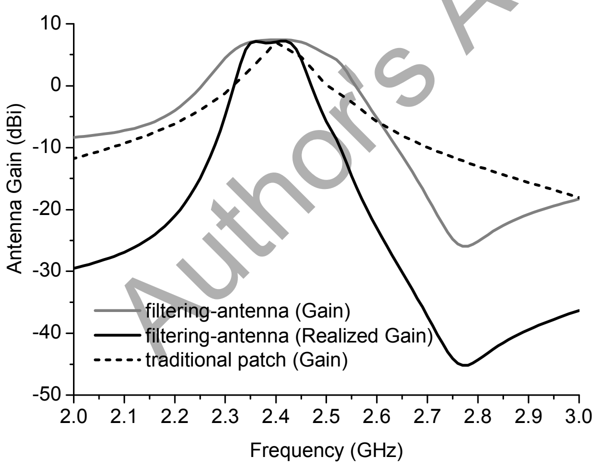


Fig. 10 The gain and realized gain of the filtering-antenna and gain of the traditional patch

IV. CONCLUSION

In this paper, a filtering antenna with improved frequency selectivity has been proposed. Compared with the traditional antenna, the integrated design of filter-antenna is much more compact with a simple structure. The bandwidth of the filter-antenna can be controlled by adjusting the dimension and feeding location of the aperture. Simulated and measured results demonstrate that this filtering antenna has a good performance in impedance matching, polarization and antenna gains. Further work will look at integration of antennas, filters and RF power amplifiers to form highly integrated RF front ends [11] [12].

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