# An Integrated Open-Loop Resonator Bandpass Filter-Slot Antenna with Stopband Improvement

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## Abstract

In this paper, a novel Integrated Filter-Antenna (IFA) is proposed. The filtering element is based on the open-loop resonator bandpass filter with capacitive termination. The slot antenna is developed by a microstrip fed slot. This slot antenna not only provides overall good antenna performance, but also improves the stopband rejection of the filter. The simulations and measurements of a 900 MHz prototype bandpass filter and a 1.8 GHz slot antenna are presented in this work. The measured results have good match with the simulation. Compared to the filter structure without slot antenna, the stopband rejection is improved by 8 dB without increase the size of the circuit.

## 1. Introduction

In the modern wireless communication system, the antenna and filter play an important role especially for radio-frequency (RF) transceivers. However, it is still challenge to fabricate a low-loss filter and antenna on a common substrate [1], and thus external independent packages are usually used for these wireless systems, as a result, the system size is larger than using the silicon chip and it would be a concern [1], [2]. Nowadays, miniaturization and low cost are the two most fundamental demands for wireless communication component design, and the desire for compact and multiple functional components is growing, a feasible solution that integrated the antenna and filter in a single module can meet the requirements. It was demonstrated by combining a horn antenna and the frequency-selective surface (FSS) for system-in-package (SIP) technology, this integrated antenna and filter in either different metallic layers or separate packages [3].

Recently, [4] and [5] report some implementations of integrated filter-antenna which based on the micorostrip fabrication technology. In [4], lowpass filter using the defected-ground-structure (DGS) microstrip line was incorporated with a dual-polarization patch antenna to form the dual-band antenna with high isolation. In addition, there are two three-port IFA modules proposed with high isolation between the filter and antenna. One is consisting of a microstrip patch antenna and a ring filter, while another one integrates a solt antenna with a U-shaped filter [5]. In this paper, an Integrated Filter-Antenna (IFA) is proposed. This IFA consists of microstrip open-loop quasi-elliptic filter with wide stopband and H-shape slot antenna, which can be placed very close to each other. It was found that the mutual coupling between the antenna and filter is low, so isolating ground layers can be eliminated. In addition, this IFA benefits better stopband rejection in the filter upper bandedge. The proposed design is particularly useful for SIP because it can reduce the size of the package and make them work effectively. Besides this introduction, there are three sections. In Section 2, the novel filter based on open-loop resonator with capacitive termination and a symmetrical wide-slot antenna is proposed. The performance, analysis of the insertion loss, return loss, isolation, transmission zeros and stopband rejection of the proposed IFA are also discussed while the experimental results are given in Section 3. Finally, a conclusion is drawn in Section 4.

# 2. Filter-Antenna Design

Fig. 1 shows the proposed three-port IFA, where the antenna and filter are integrated in a single substrate. Port 1 and Port 2 are the input and output ports respectively of the filter whilst Port 3 is the antenna port. The operating frequency of filter is $f_1$, and which is different from the antenna frequency $f_2$.

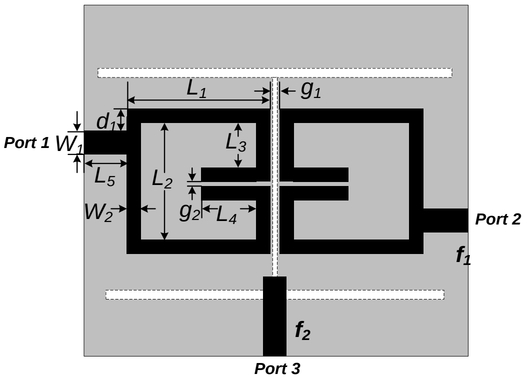


Fig. 1 Layout of the proposed IFA

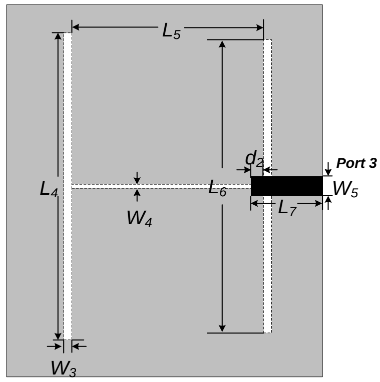


Fig. 2 Layout of the H-shaped slot antenna

## A. Open-loop Resonator Bandpass Filter Design

Followed the traditional open-loop resonator bandpass filter design [6], capacitive terminations are realized by low characteristic impedance microstrip open stub so as to obtain the compact size and spurious suppression. To design a filter at 900 MHz, the dimensions of the filter as shown in Fig. 1 are determined and optimized with $L_1$ = 22.5 mm, $L_2$ = 21.5 mm, $L_3$ = 12.5 mm, $L_4$ = 8 mm, $L_5$ = 8 mm, $W_1$ = 3 mm, $W_2$ = 2 mm, $d_1$ = 4.5 mm, $g_1$ = 1.1 mm, $g_2$ = 0.5 mm. The total length of open-loop $2L_1+L_2$ is $\lambda/2$ for the filter operating frequency; the width of open-loop $W_1$ is identical to 50 Ω microstrip line. Based on the above filter dimensions, the simulated S-parameter of the filter structure without antenna is shown in Fig. 3.

In Fig. 3, the simulated insertion and return losses of the filter are about 1.6 dB and 21.7 dB at the centre frequency of 0.898 GHz respectively. The fractional bandwidth is 3% and two transmission zeros are located at 0.88 GHz and 0.91 GHz near the lower and upper band edges proximity at 1 GHz and 2.06 GHz. In addition, two zeros in the stopband are resulted in 2.1 GHz and 2.4 GHz.

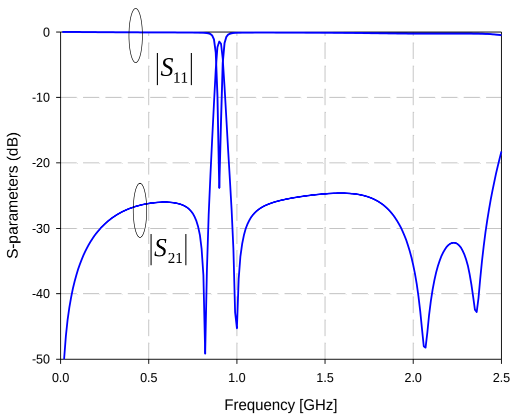


Fig. 3 The simulated S-parameters of the open-loop resonator filter

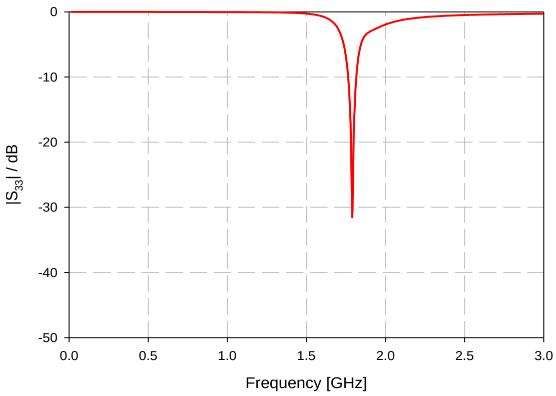


Fig. 4 The simulated return loss of the antenna

## B. Slot Antenna Design

Besides the filter, Fig. 2 depicts the layout of the proposed H-shaped microstrip-fed slot antenna, which an H-shaped slot radiator is formed on the ground plane, while the feed line is extended perpendicularly cross the slot in the middle on the top of the dielectric substrate. According to the simulations, $L_5$ has no obvious effect on the slot antenna while it incorporates with the slot $L_4$ can control the stopband rejection of the filter in upper sideband. The coupling point for the slot radiator is determined by the offset distance $d_2$, from the centre of the feed line resonator to adjust the required coupling degree between these two resonators in optimization design. According to the above design of the H-shape slot antenna, the dimensions of a 1.8 GHz antenna in Fig. 2 can be optimized and these are $L_4$ = 59 mm, $L_5$ = 39.5 mm, $L_6$ = 57 mm, $L_7$ = 23.75 mm, $W_3$ = 1 mm, $W_4$ = 0.5 mm, $W_5$ = 2 mm, $d_2$ = 2.5 mm. Fig. 4 shows the simulated S-parameters of the slot antenna. The simulated return loss of this slot-antenna is 31.52 dB at 1.8 GHz.

*C. Filter-Antenna Design*

Besides the individual studies of the filter and antenna in previous sub-sections, the performance of the integrated filter-antenna is studied in this section and the simulated S-parameters are recorded in Fig. 5 (a). The simulated insertion and return losses of the filter are about 2.4 dB and 18.8 dB at the centre frequency of 900 MHz respectively, while the fractional bandwidth is 2.8%. The simulated operating frequency of the slot antenna is 1.79 GHz, and the impedance bandwidth ($|S_{33}|$ < -10 dB) is 3%. Compared to the response of the individual filter and antenna as shown in Fig. 5(a), it is obvious that the filter and antenna performances are no significant affect for the IFA, although the transmission zeros are shifted from 0.88 GHz and 0.91 GHz to 0.84 GHz and 1.1 GHz respectively. However, the IFA has improved the upper stopband rejection by around 8 dB within 1 GHz to 2 GHz frequency range. The upper stopband rejection of the filter without antenna is around 24 dB between 1.1 GHz and 1.8 GHz while more than 32 dB is recorded for the upper stopaband of IFA.

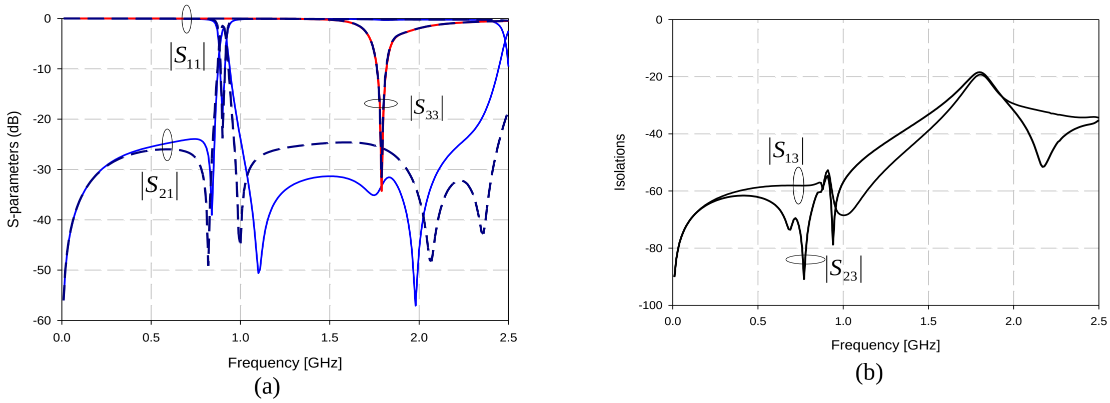


Fig. 5. (a) The simulated S-parameters of the IFA. (IFA —, individual filter and antenna - - -); (b) The isolations of the filter and antenna of the IFA

It is noted that the isolation is about 20 dB at the slot antenna operating frequency while the isolations of this IFA generally maintains larger than 50 dB below 1.2 GHz. It is demonstrated that the filter and antenna work independently without significant performance degrade and any circuit size increasing.

## 3. Experimental Results

To demonstrate the proposed IFA, a prototype is fabricated as shown in the inset of Fig. 6 (b). The substrate used is RO4003 with relative dielectric constant of 3.38 and a thickness of 1.524 mm. The measurement results of the insertion loss, return loss and isolation are shown in Fig. 6 (a). The measured insertion and return losses of the filter is about 2.2 dB and 16.1 dB at the centre frequency of 874 MHz, and the fractional bandwidth is 6.8%. There are two transmission zeros located at 0.8 GHz and 1.14 GHz as expected. The measured operating frequency of the slot antenna is 1.76 GHz, and the 10-dB impedance bandwidth is 2.3%. The frequency shift in measurement is about 20 MHz both on filter and slot antenna. The stopband rejection is about 30 dB, and at the antenna operating frequency, the stopband rejection can be better than 35 dB. Fig. 6 (b) plots the isolation of the IFA.

The isolation is higher than 50 dB at the filter operating frequency. These results confirm the proposed IFA usefulness.

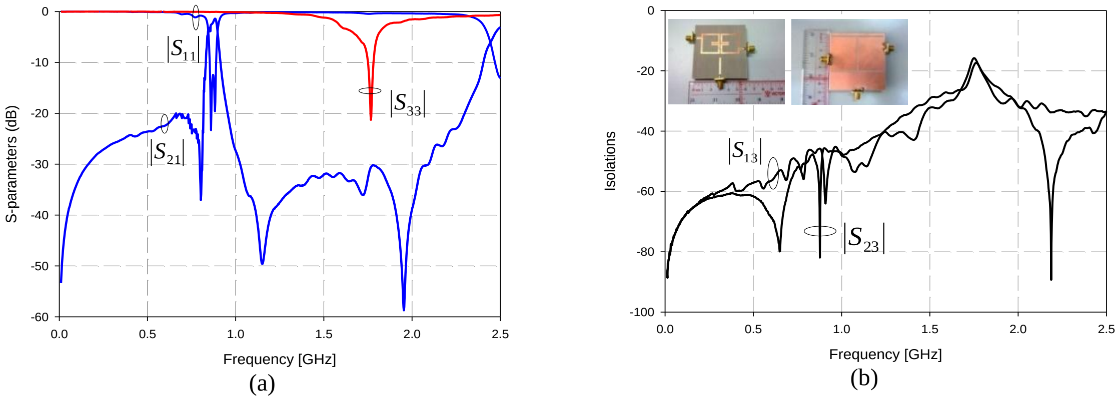


Fig. 6. (a) The measured S-parameters of the prototype. (b) The isolation of IFA

## 4. Conclusion

This paper presents a novel integrated-filter-antenna (IFA), the filter is based on the open-loop resonator bandpass filter with capacitive termination, the slot antenna is developed by a symmetrical wide-slot radiator and a microstrip feeding. The isolation between the antenna and filter parts of the IFA is very large; therefore, the two parts can be designed almost independently.

## Acknowledgments

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