Novel Filter-Antenna using Slot Antenna and Centrally Loaded Coupled Line Structure

Wen-Yao Zhuang[1], Pedro Cheong, Wai-Wa Choi and Kam-Weng Tam

Department of Electrical and Electronics Engineering
Faculty of Science and Technology, University of Macau
Av. Padre Tomás Pereira Taipa, Macao SAR, China
[1]*ma96513@umac.mo*

Abstract

In this paper, a novel Integrated Filter-Antenna (IFA) is presented. The filtering element is based on the simple quasi-elliptic bandpass filter with capacitive loading, in which the fundamental resonance is significantly attenuated and thus the intrinsic harmonic resonance associated with two zeros is deliberately utilized to realize a quasi-elliptic bandpass response with simultaneous control of zeros and bandwidth. The slot antenna is developed by a symmetrical C-shaped slot and a microstrip fed line which feds at the center. The simulations and measurements of a 2.4 GHz prototype bandpass filter and a 2 GHz slot antenna are presented in this work. The isolations between the filter and the antenna are better than 20 dB.

Keywords: Quasi-elliptic microstrip bandpass filter, slot antenna.

1. Introduction

In the modern wireless communication system, the antenna and filter play a key role and widely adopted in industry. 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].

The latest developments of the technology report some implementations of integrated filter-antenna which based on the microstrip fabrication technology. In [4], 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 slot antenna with a U-shaped filter. A 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 [5]. And it was found that the isolations between the antenna and filter part of the IFA are very small [6]. In this paper, the proposed IFA consists of microstrip quasi-elliptic filter with wide stopband and C-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. 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 quasi-elliptic resonator with capacitive loading 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

A. Quasi-Elliptic Bandpass Filter Design

Fig. 1 shows the proposed three-port IFA, where the antenna and filter are integrated in a single substrate, and Port 1 and Port 2 are the input and output ports respectively of the filter. A simple parallel-coupled line model with circuitry node numbering has been proposed in Fig. 2, the electrical length of the transmission line is $\lambda/2$. Assume unity dielectric constant and identical characteristic impedance, Fig. 2 also shows the transmission line response in terms of $|S_{21}|$. Because of the periodicity of frequency response of the coupled-

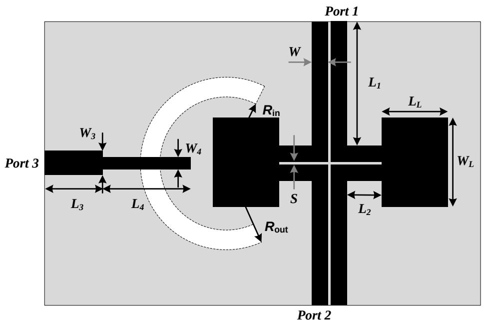


Fig. 1 Proposed IFA implementation.

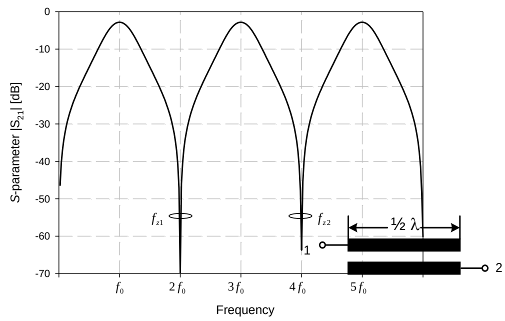


Fig. 2 The transmission line response in terms of $|S_{21}|$.

line, the harmonic response located at nf_0 where n = 3, 5, 7, 9, ... Different from the fundamental passband at f_0, the other harmonic passband is bounded by a pair of finite transmission zeros at frequencies f_{z1} and f_{z2} yielding quasi-elliptic bandpass response indeed.

In order to achieve a sharp stopband response, the first harmonic passband is selected and the fundamental passband have to be eliminated. It results from increasing the self-coupling in each part of the transmission line and decreasing the parallel coupling. As such, the fundamental passband attenuates significantly but enhances coupling of the first harmonic passband, and hence the fundamental response is suppressed obviously. On the other hand, the miniaturization technique for parallel-coupled line has been used, which is the capacitive loading on the resonator to shrink the coupled-line. Moreover, a larger capacitive loading also leads to lower the frequency of the first harmonic. Additional transmission zeros can be generated to proper control the electrical lengths of the self-coupled sections and loading capacitances, and benefit better stopband rejection.

Based on the above method, a novel parallel-coupled line filter is proposed in Fig. 1. It replicates the classical parallel-coupled section with capacitive load. The dimensions of the filter as shown in Fig. 1 are determined and optimized with L_1 = 15.39 mm, L_2 = 4.32 mm, L_L = 11 mm, W = 2 mm, W_L = 11 mm, S = 0.36 mm, and Fig. 3 plots the simulation result of this filter. Two transmission zeros are located at 2.06 GHz and 2.67 GHz whilst 6% at 2.42 GHz as fractional bandwidth. The simulated mid-band insertion loss of this filter is recorded at 0.97 dB with around 29.53 dB return loss. The upper stopband rejection is better than 27 dB while around 25 dB attenuation in the lower stopband.

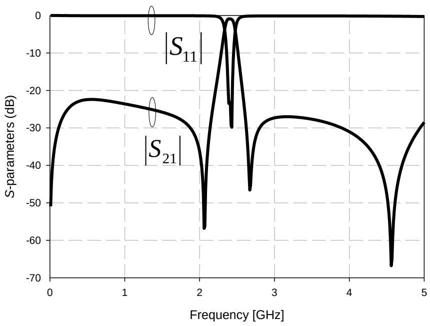


Fig. 3 The simulated *S*-parameters of the Quasi-elliptic parallel-coupled line bandpass filter.

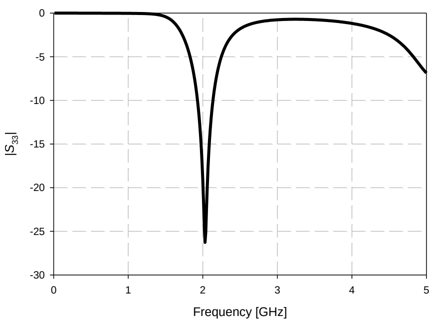
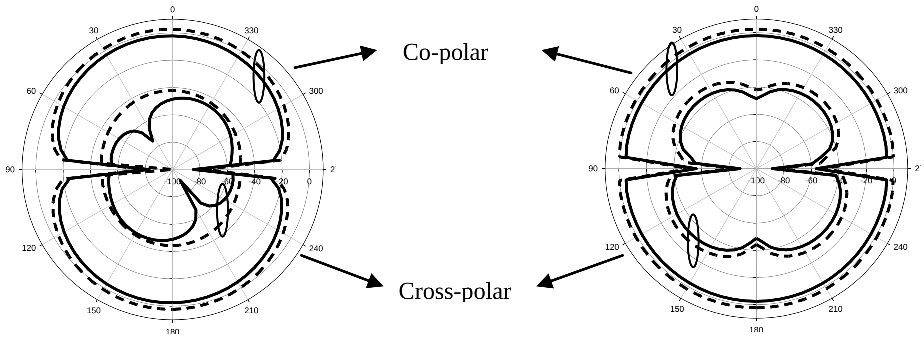


Fig. 4 The simulated $|S_{33}|$ of the C-shaped slot antenna.

B. Slot Antenna Design

Besides the filter, Fig. 1 also depicts the layout of the proposed C-shaped microstrip-fed slot antenna, where a C-shaped slot radiator is formed on the ground plane, and the feed line is extended perpendicularly cross the slot in the middle on the top of the dielectric substrate. The C-shaped slot patch is chosen because it produces a large bandwidth. In this design, the slot is constructed by a partial ring slot resonator, and the radian is about π. The operating frequency is determined by the length of the slot and the location of the feed-line. The length of the feed-line has no significant effect in the slot antenna. The dimensions of a 2 GHz antenna in Fig. 1 can be optimized and these are L_3 = 7.2 mm, L_4 = 11.1 mm, W_3 = 3 mm, W_4 = 1.5 mm, R_{in} = 10 mm, R_{out} = 13 mm, and the radian of the slot is about 1.5π. Fig. 4 shows the simulation result of this antenna, the matching of the antenna is located at 2.02 GHz with 26.3 dB return loss, the impedance bandwidth ($|S_{33}|$ < -10 dB) is about 10%. The simulated radiation patterns of the slot antenna are illustrated in Fig. 5, and the gain can reach as much as 2.7 dBm.



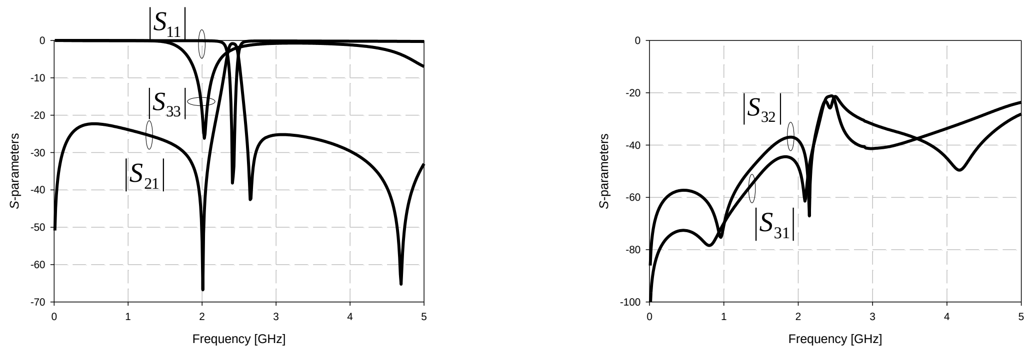
E-plane H-plane

Fig. 5 Simulated radiation patterns of slot antenna (---) alone and slot antenna of the proposed IFA (—) at 2.02 GHz.

C. Filter-Antenna Design

Besides the separated performance studies of the filter and antenna in previous sub-sections, the performance of the integrated filter-antenna is studied and the simulated *S*-parameters are depicted in Fig. 6(a). The simulated insertion and return losses of the filter are about 0.85 dB and 38.2 dB at the centre frequency of 2.41 GHz respectively, with the fractional bandwidth of 6.1%. The simulated operating frequency of the slot antenna is 2.02 GHz, and the impedance bandwidth is 10%. Compared to the response of the individual filter and antenna, it is obtained that the filter and antenna performances are no significant affect the IFA, although the transmission zeros are shifted from 2.06 GHz and 2.67 GHz to 2.0 GHz and 2.65 GHz respectively. The radiation patterns are shown in Fig. 5, and it is similar with the result of the slot antenna alone, however, the antenna gain in the IFA is decreased.

The isolation is more than 20 dB at the filter operating frequency while the isolations of this IFA generally maintains larger than about 40 dB below 2 GHz. It is demonstrated that the filter and antenna work independently without significant performance degrade and any circuit size increasing.



(a) (b)

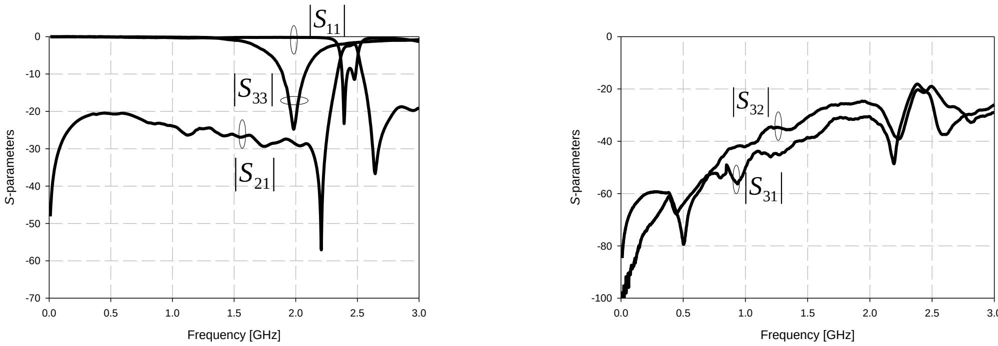
Fig. 6 (a) The simulated *S*-parameters of the IFA; (b) The isolations between the filter and antenna of the IFA.

3. Experimental Results

Based on the discussion in Section 2, a prototype is fabricated as shown in the Fig. 7, using a RO4003 substrate with relative dielectric constant of 3.38 and a thickness of 0.8128 mm. The measurement results of the insertion loss, return loss and isolation are shown in Fig. 8. The measured insertion and return losses of the filter is about 3.0 dB and 23.28 dB at the centre frequency of 2.39 GHz, and the fractional bandwidth is 6.5%. There are two transmission zeros located at 2.20 GHz and 2.64 GHz as expected. The measured operating frequency of the slot antenna is 1.97 GHz with 24.8 dB matching, and the 10 dB impedance bandwidth is 9.25%. The frequency shift in measurement is about 10 to 30 MHz both on filter and slot antenna. The stopband rejection is about 30 dB at the antenna operating frequency. Fig. 8(b) plots the isolation of the IFA. The isolation between the filter and antenna are all below 20 dB.

(a) (b)

Fig. 7 The prototype of the IFA. (a) Top view; (b) Bottom view.



(a) (b)

Fig. 8. (a) The measured *S*-parameters of the prototype. (b) The isolation of IFA.

4. Conclusion

In this paper presents a novel integrated-filter-antenna (IFA), the filter is based on the quasi-elliptic microstrip bandpass filter with load self-coupled section so as to take full advantage of the intrinsic quasi-elliptic bandpass response at the first harmonic frequency. 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 large. This novel structure can be easily constructed and the presented example also demonstrates the usefulness of this approach.

Acknowledgments

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