An Integrated Approach to RF Antenna-Filter Co-Design
Jianhong Zuo, Xinwei Chen, Guorui Han, Li Li, and Wenmei Zhang, Member, IEEE

Abstract—In this letter, a co-designed antenna-filter is presented. The antenna-filter is composed of a microstrip patch antenna and a hairpin filter, both of which share the same ground plane to reduce the size. Instead of using the traditional 50-Ω interfaces, the impedance between the filter and antenna is optimized to improve the performance. The simulated and measured results have demonstrated that co-designed antenna-filter has a better bandwidth (4.7%, 4.06-4.26 GHz) and a larger gain (4.3 dBi) than the traditional version with 50-Ω interfaces impedance.

Index Terms—Antenna, co-design, filter.

I. INTRODUCTION

MINIATURIZATION and low cost are the two most fundamental demands for RF receiver front-ends. One way to miniaturize an RF front-end is to embed its passive circuitries and interconnects into a package, which is called system-in-package (SIP) [1], [2]. Another way is to integrate required multiple functional circuits into one device without the 50-Ω (or 75-Ω) constraints, referred to as co-design [3]–[10]. The co-design method can change the structure of the circuit, improve the performance of the circuits, and simplify the connections between different components. For example, the noise figure of a RF antenna-filter-LNA system has been significantly improved with the co-design strategy [3]. In [4] and [5], antennas were co-designed with an amplifier and transceiver to attain higher integration degree. Similarly, an RF device was implemented by integrating three-dimensional (3-D) cavity filters/duplexers and antennas [6]. In [7], the resonator of an antenna also acted as an element of filter. In [8] and [9], a coplanar antenna-filter was co-designed. In [10], a two-pole filter was realized by integrating a filter and an antenna.

In this letter, a co-designed antenna-filter is presented. A microstrip patch antenna is layered on the top of a hairpin filter, and they share the same ground plane. A via hole is implemented to connect the antenna and the filter. The impedance at the interfaces is optimized to improve the performance of the antenna-filter, without restricting to 50 Ω. The proposed antenna-filter operates in the frequency band 4.06–4.26 GHz, and the bandwidth for \( |S_{11}| \leq -10 \) dB is 4.7%. The simulated and measured results indicate that the proposed co-design approach can be used to reduce the size, improve the bandwidth, and increase the radiation gain.

II. CO-DESIGN OF ANTENNA AND FILTER

The configurations of the traditional and the co-designed antenna-filters are shown in Fig. 1. Unlike the traditional antenna-filter in which the components are cascaded with 50-Ω interfaces [Fig. 1(b)], our co-designed antenna-filter is assembled vertically and connected using a metallized via hole, as shown in Fig. 1(a). Also, the ground plane is sandwiched in the middle and shared by both the antenna and the filter. With this configuration, the size of the whole device can be significantly reduced. In order to avoid the electromagnetic (EM) interference between the antenna and the filter, they are arranged to have the parallel current. Furthermore, the impedance at the interfaces is optimized by adjusting the location and dimension of the via hole to attain better performance.

A. Filter Design

Fig. 2 shows the configuration of our hairpin filter. The filter is designed to have a fractional bandwidth (FBW) of 6% at 3.95 GHz. We choose a two-pole \( (n = 2) \) butterworth low-pass filter prototype with a pass-band ripple of 3.01 dB. The low-pass prototype parameters include \( g_0 = 1.0, g_1 = 1.4142, g_2 = 1.4142, \) and \( g_3 = 1 [11] \). Based on the low-pass parameters, the design parameters of the band-pass can be calculated by

\[
Q_{el} = \frac{g_0 g_1}{FBW}, \quad Q_{en} = \frac{g_2 g_{n+1}}{FBW}, \\
M_{i+k+1} = \frac{FBW}{g_{i+k+1}} \text{ for } i = 1 \text{ to } n - 1
\]

(3.1)

where \( Q_{el} \) and \( Q_{en} \) are the external quality factors of the resonators at the input and output port, and \( M_{i+k+1} \) are the coupling coefficients between the \( i \)th and \( (i+1) \)th resonators. For this design, we have \( Q_{el} = 23.57, Q_{en} = 23.57, \) and \( M_{1,2} = 0.042 \). It should be noted that the designed hairpin resonators have a line width \( (l_2) \) of 3 mm and a separation \( (l_3) \) of 7 mm between the two arms. Another dimension of the resonator, indicated by \( l_1 \), is about \( \lambda_{0}/4 (\lambda_{0}, \text{the guided wavelength at the central frequency}) \), and in this case, \( l_1 = 23.5 \) mm.

In our design, the optimized dimensions of the proposed filter are \( \varepsilon_{1,2} = 4.4, h_1 = 0.8 \) mm, \( w_1 = 2.24 \) mm, \( w_2 = 12.76 \) mm.
Fig. 1. Antenna-filter with (a) co-design version, (b) traditional version.

Fig. 2. The configuration of the hairpin filter.

Fig. 3. $S$ parameters for the filter.

$w_3 = 16$ mm, $w_4 = 17$ mm, $w_5 = 3$ mm, $l_1 = 23.5$ mm, $b_2 = 3$ mm, $l_3 = 7$ mm, $l_4 = 2$ mm, $d_1 = 0.5$ mm, and $t = 9.64$ mm. Fig. 3 shows the $S$ parameters of the filter. We can observe that the simulated and measured center frequency for the filter is 3.92 and 4.03 GHz, respectively.

B. Antenna Design

The structure of the microstrip patch antenna with two rectangular notches is shown in Fig. 4. The antenna is designed to operate at the center frequency of 3.95 GHz, and the rectangular notches are used to improve the bandwidth. The optimized design parameters for the antenna with 50-$\Omega$ interface impedance are $\varepsilon_{r1} = 3.4$, $h_2 = 0.8$ mm, $a_1 = 30$ mm, $b_1 = 20$ mm, $a_2 = 1$ mm, $b_2 = 2$ mm, and $b_4 = 9$ mm. The measured and simulated results are shown in Fig. 5. We can see that the bandwidth of antenna with notches is 2.8%, which is better than that without notches.
III. SIMULATED AND MEASURED RESULTS FOR CO-DESIGN ANTENNA-FILTER

With the designs of antenna and filter shown in Section II, the co-designed antenna-filter [shown in Fig. 1(a)] is implemented. We also optimize the location and dimension of the via hole, the coupling between via and ground plane, and the impedance at the interface of the antenna and the filter. The optimized dimensions of co-designed antenna-filter include $a_3 = 20$ mm, $b_3 = 6$ mm, $u_3 = 1.6$ mm, $l_5 = 1.6$ mm, and $r = 0.6$ mm, while the other parameters are the same as those in Section II. The commercial software Ansoft Designer (SV) is used to simulate the antenna-filter, and the Agilent N5230A vector network analyzer and the MS2668C spectrum analyzer are used to measured the device.

Fig. 6 shows the measured and simulated $S_{11}$ parameters for the co-designed and traditional antenna-filters. It can be seen for the co-designed version that the measured pass-band is located at 4.06–4.26 GHz (the impedance bandwidth is 4.7%), as compared to 4.03–4.14 GHz for the traditional version. Obviously, due to the better coupling between the antenna and the filter, as well as via hole and ground plane, two resonant frequencies (4.08 and 4.18 GHz) appear that show the co-designed version has a broader bandwidth.

The radiation patterns of the proposed antenna-filter are also measured, and the results at 4.08 and 4.18 GHz are shown in Figs. 7 and 8, respectively. In addition, the measured results for the single antenna at 4 GHz are also presented in Fig. 9. The
results indicate that the co-designed antenna-filter has different radiation performances at 4.08 and 4.18 GHz. At 4.08 GHz, it shows good omnidirectional in E- and H-plane, while it has a similar radiation characteristic at 4.18 GHz as the single antenna.

Finally, the measured gains from 3.8 to 4.3 GHz are shown in Fig. 10. It can be seen that the gain of co-designed antenna-filter is larger than 2.8 dBi in the bandwidth of $|S_{11}| \leq -10$ dB, and the peak gain is 4.3 dBi better than 2.8 dBi of the traditional version.

IV. CONCLUSION

A co-designed antenna-filter is presented. The simulated and measured results demonstrate the co-design can be used to improve the bandwidth and the gain of the antenna and reduce the size of device.

REFERENCES


射频和天线设计培训课程推荐

易迪拓培训(www.edatop.com)由数名来自于研发第一线的资深工程师发起成立，致力并专注于微波、射频、天线设计研发人才的培养；我们于2006年整合合并微波EDA网(www.mweda.com)，现已发展成为国内最大的微波射频和天线设计人才培养基地，成功推出多套微波射频以及天线设计经典培训课程和ADS、HFSS等专业软件使用培训课程，广受客户好评；并先后与人民邮电出版社、电子工业出版社合作出版了多本专业图书，帮助数万名工程师提升了专业技术能力。客户遍布中兴通讯、研通高频、埃威航电、国人通信等多家国内知名公司，以及台湾工业技术研究院、永业科技、全一电子等多家台湾地区企业。

易迪拓培训课程列表：http://www.edatop.com/peixun/rfe/129.html

射频工程师养成培训课程套装

该套装精选了射频专业基础培训课程、射频仿真设计培训课程和射频电路测量培训课程三个类别共30门视频培训课程和3本图书教材：旨在引领学员全面学习一个射频工程师需要熟悉、理解和掌握的专业知识和研发设计能力。通过套装的学习，能够让学员完全达到和胜任一个合格的射频工程师的要求…

课程网址：http://www.edatop.com/peixun/rfe/110.html

ADS学习培训课程套装

该套装是迄今国内最全面、最权威的ADS培训教程，共包含10门ADS学习培训课程。课程是由具有多年ADS使用经验的微波射频与通信系统设计师资深专家讲解，并多结合设计实例，由浅入深、详细而又全面地讲解了ADS在微波射频电路设计、通信系统设计和电磁仿真设计方面的内容。能让您在最短的时间内学会使用ADS，迅速提升个人技术能力，把ADS真正应用到实际研发工作中去，成为ADS设计专家…


HFSS学习培训课程套装

该套课程套装包含了本站全部HFSS培训课程，是迄今国内最全面、最专业的HFSS培训教程套装，可以帮助您从零开始，全面深入学习HFSS的各项功能和在多个方面的工程应用。购买套装，更可超值赠送3个月免费学习答疑，随时解答您学习过程中遇到的棘手问题，让您的HFSS学习更加轻松顺畅…

课程网址：http://www.edatop.com/peixun/hfss/11.html
专注于微波、射频、天线设计人才的培养
网址：http://www.edatop.com

CST 学习培训课程套装
该培训套装由易迪拓培训联合微波EDA网共同推出，是目前最全面、系统的CST微波工作室培训课程套装，所有课程都由经验丰富的专家授课，视频教学，可以帮助您从零开始，全面系统地学习CST微波工作的各项功能及其在微波射频、天线设计等领域的设计应用。且购买该套装，还可超值赠送3个月免费学习答疑…

HFSS 天线设计培训课程套装
套装包含6门视频课程和1本图书，课程从基础讲起，内容由浅入深，理论介绍和实际操作讲解相结合，全面系统的讲解了HFSS天线设计的全过程。是国内最全面、最专业的HFSS天线设计课程，可以帮助您快速学习掌握如何使用HFSS设计天线，让天线设计不再难…
课程网址：http://www.edatop.com/peixun/hfss/122.html

13.56MHz NFC/RFID线圈天线设计培训课程套装
套装包含4门视频课程，培训将13.56MHz线圈天线设计原理和仿真设计实践相结合，全面系统地讲解了13.56MHz线圈天线的工作原理、设计方法、设计考量以及使用HFSS和CST仿真分析线圈天线的具体操作，同时还介绍了13.56MHz线圈天线匹配电路的设计和调试。通过该套课程的学习，可以帮助您快速学习掌握13.56MHz线圈天线及其匹配电路的原理、设计和调试…

我们的课程优势：
※ 成立于2004年，10多年丰富的行业经验,
※ 一直致力并专注于微波射频和天线设计工程师的培养，更了解该行业对人才的要求
※ 经验丰富的一线资深工程师讲授，结合实际工程案例，直观、实用、易学

联系我们：
※ 易迪拓培训官网：http://www.edatop.com
※ 微波EDA网：http://www.mweda.com
※ 官方淘宝店：http://shop36920890.taobao.com

专注于微波、射频、天线设计人才的培养
官方网站：http://www.edatop.com
淘宝网店：http://shop36920890.taobao.com