A Novel Low-Pass Filter With an Embedded Band-Stop Structure for Improved Stop-Band Characteristics

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A Novel Low-Pass Filter With an Embedded Band-Stop Structure for Improved Stop-Band Characteristics

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***Abstract*—This letter presents a novel design of a microstrip low-pass filter (LPF) with an embedded band-stop structure, which is constructed from a simple two transmission line band-stop filter. The band-stop structure is ingeniously embedded into a classical step-impedance microstrip LPF. The stop-band of the proposed LPF is more than two times broader than the original design, while its cut-off frequency remains at 1.8 GHz. The embedded structure does not increase the physical dimension of the LPF, but improves the performance significantly. Measured results agree with simulation well, and validate the dual-frequency design method.**

***Index Terms*—Band-stop filters, low-pass filters (LPFs), microstrip.**

I. INTRODUCTION

MICROSTRIP low-pass filters (LPFs) have been widely used in microwave systems to block unwanted high frequency harmonics and/or inter-modulations. The conventional transmission line based LPFs, such as open stub filters and step-impedance filters, always suffer from gradual cutoff attenuation skirt and narrow upper stop bandwidth [1]. It is usual to increase the order of a LPF with large size and accumulated insertion loss to sharpen the skirt effect. Some ground etching techniques are taken to widen the upper stop-band [2], [3]. Step-impedance hairpin resonators [4], semi-lump filters [5], and coupled line hairpin resonators [6] are used to sharpen the cut-off and widen the upper stop band in some recent research.

Fig. 1(a) shows a simple band stop filter [7], which contains two parallel sections of microstrip lines. Z_1, Z_2, θ_1 and θ_2 are characteristic impedance and electric lengths of those two microstrip lines, respectively. Fig. 1(b) shows a modified band-stop structure, which is derived from Fig. 1(a). A section of parallel coupled line is introduced. $Z_{0e}, \theta_{0e}, Z_{0o}$, and θ_{0o} are the characteristic impedance and electric lengths of even and odd modes of the parallel coupled line, respectively.

In this letter, a compact LPF with wide stop band is designed based on classic step-impedance LPF. The proposed filter keeps the size unchanged, while a band-stop structure in Fig. 1(b) is ingeniously embedded into the LPF to improve its stop-band response.

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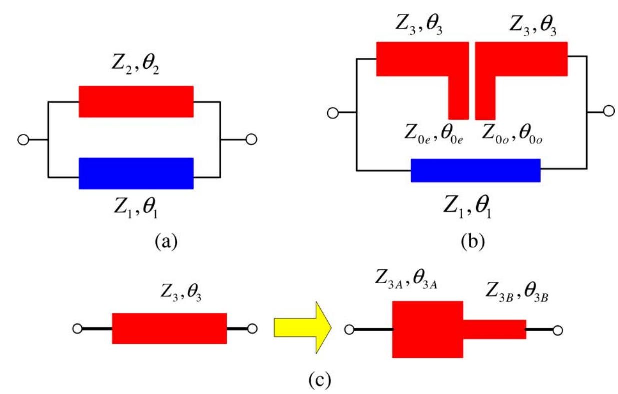


Fig. 1. (a) Simple band-stop filter in [7]. (b) The proposed band-stop structure. (c) Transforming a uniformed transmission line into a step-impedance line.

II. FILTER DESIGN

A classical step-impedance microstrip LPF with the cut-off frequency f_c is designed first. Then, a band-stop structure with the center stop-band frequency at about 3 f_c is designed and appropriately embedded into the LPF. The size and the cut-off frequency of the LPF remain unchanged, while the stop-band is extended significantly.

The proposed band-stop structure is shown in Fig. 1(b), in which the transmission line Z_2, θ_2 in Fig. 1(a) is replaced by two transmission lines Z_3, θ_3 and one parallel coupled transmission line $Z_{0e}, \theta_{0e}, Z_{0o}, \theta_{0o}$. The transmission zeroes of the basic band-stop filter in Fig. 1(a) satisfy

$$Z_1 \sin\theta_1 = -Z_2 \sin\theta_2. \tag{1}$$

A wide stop band is obtained, when $\theta_1 = m\pi$ and $\theta_2 = \mathrm{n}\pi$, where m and n are positive integers, as discussed in [7]. All electrical lengths here are referenced at the center frequency of the stop-band.

Find the ABCD matrix of the parallel coupled lines [8], and let the ABCD matrice of those two circuits in Fig. 1 equal to each other. We get

$$\begin{bmatrix} \cos\theta_2 & jZ_2\sin\theta_2 \\ j\frac{\sin\theta_2}{Z_2} & \cos\theta_2 \end{bmatrix} = \begin{bmatrix} \cos\theta_3 & jZ_3\sin\theta_3 \\ j\frac{\sin\theta_3}{Z_3} & \cos\theta_3 \end{bmatrix} \times \begin{bmatrix} A' & B' \\ C' & D' \end{bmatrix} \begin{bmatrix} \cos\theta_3 & jZ_3\sin\theta_3 \\ j\frac{\sin\theta_3}{Z_3} & \cos\theta_3 \end{bmatrix} \tag{2}$$

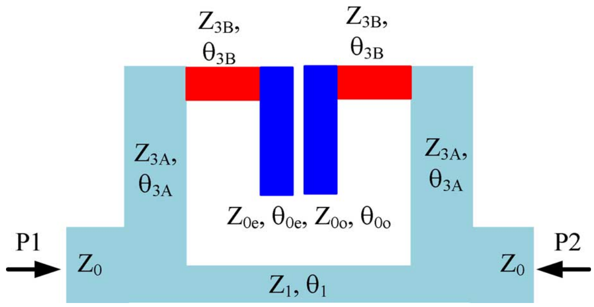


Fig. 2. Scheme of the proposed LPF.

where

$$A' = \frac{G+1}{G-1} = D', \quad B' = -j\frac{2Z_{0e}\cot\theta_4}{G-1},$$
$$C' = j\frac{2\tan\theta_4}{Z_{0o}(G-1)}, \quad G = Z_{0e}/Z_{0o}, \text{and}$$
$$\theta_4 = \frac{\theta_{0e}+\theta_{0o}}{2}.$$

Let $Z_2 = Z_3$ and $\theta_2 = 2n\pi$ at the desired stop-band center frequency f_0 to construct a band stop filter. Equation (2) could be simplified as

$$(G+1)Z_2\sin 2\theta_3 = 2\frac{Z_2^2}{Z_{0o}}\tan\theta_4\sin\theta_3^2 + 2Z_{\text{oe}}\cot\theta_4\cos\theta_3^2. \quad (3)$$

Furthermore, the transmission line Z_3, θ_3 shown in Fig. 1(b) could be transformed into step impedance lines [9] $Z_{3\text{A}}, \theta_{3\text{A}}, Z_{3\text{B}}, \theta_{3\text{B}}$ (electrical lengths are at f_0) shown in Fig. 1(c).

The relations between them are

$$\cos\theta_3 = \cos\theta_{3A}\cos\theta_{3B} - \frac{Z_{3A}}{Z_{3B}}\sin\theta_{3A}\sin\theta_{3B} \quad (4)$$
$$Z_3\sin\theta_3 = Z_{3B}\cos\theta_{3A}\sin\theta_{3B} + Z_{3A}\sin\theta_{3A}\cos\theta_{3B}. \quad (5)$$

The proposed LPF is shown in Fig. 2, and the design procedure is as the followings:

1) Design a step-impedance LPF
Design a classic LPF and use the step-impedance realization to determine $Z_1, \theta_1, Z_{3\text{A}}$ and $\theta_{3\text{A}}$, respectively, which indicate the series inductance and parallel capacitance.
2) Introduce a transmission zero
Choose the rejection center frequency f_0 at the first pass-band of the LPF by electromagnetic simulation. Renormalize θ_1 and $\theta_{3\text{A}}$ at f_0, and shift f_0 to make $\theta_1 = \pi$ to assure a transmission zero around the first pass-band of the LPF.
3) Embedding a band-stop filter
Choose $Z_{3\text{B}}, Z_{0\text{e}}$, and $Z_{0\text{o}}$ as proper values could be realized in physical dimension, and substitute them into (3)–(5) to determine θ_4, θ_3, and $\theta_{3\text{B}}$.

The LPF is basically composed of transmission lines Z_1, θ_1, and $Z_{3\text{A}}, \theta_{3\text{A}}$ (light-colored regions in Fig. 2), which is designed at the cut-off frequency f_{c}. The upper branch, which contains the step-impedance transmission lines $Z_{3\text{A}}, \theta_{3\text{A}}$, and $Z_{3\text{B}}, \theta_{3\text{B}}$ (in red), and the parallel coupled transmission lines (in dark blue), is equivalent to a section of transmission line. The lower branch and upper branch together form a band-stop structure, which is designed at $f_0 \approx 3f_c$. Thus, the performance of the LPF is improved remarkably with the dual-frequency design.

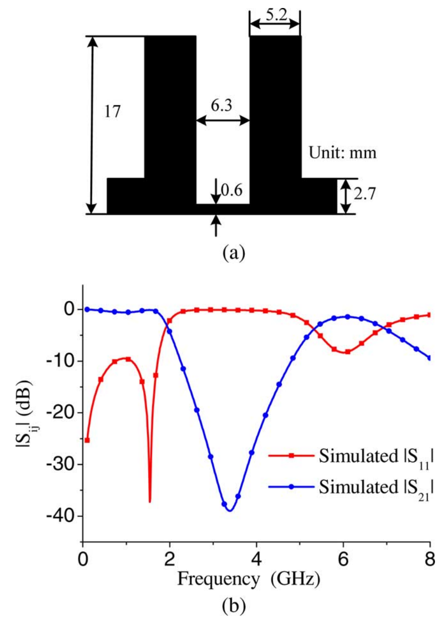


Fig. 3. Layout and simulation of the step-impedance LPF.

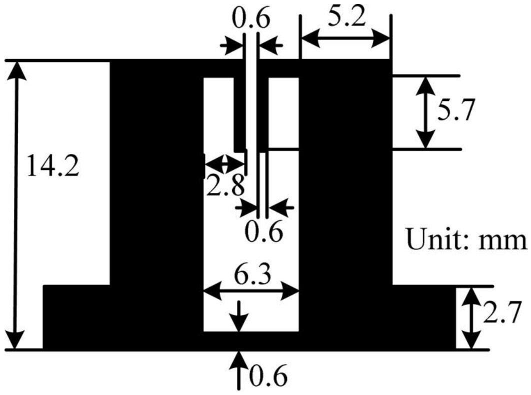
III. Experiments

Following the design procedure in Section II, a Chebyshev LPF of the third order and with 0.5 dB pass-band ripples is designed in microstrip type. The high- and low- impedance are 110 Ohm and 12 Ohm, respectively. The cut-off frequency f_{c} of the LPF is 1.8 GHz. The microstrip LPF is realized on a substrate with relative dielectric constant $\varepsilon_{\text{r}} = 2.65$ and thickness of $\text{h} = 1$ mm. The layout of the step-impedance LPF and the simulated frequency response are shown in Fig. 3(a) and (b), respectively.

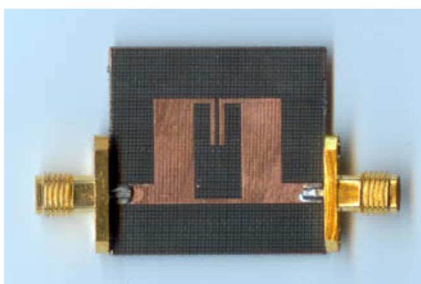
To obtain a wide rejection band, $f_0 = 6$ GHz is chosen as the center frequency of the embedding band-stop structure. Then, $\text{Z}_1 = 110\ \Omega$ and $\text{Z}_2 = 70\ \Omega, \theta_1 = \pi$, and $\theta_2 = 2\pi(\text{m} = 1$ and $\text{n} = 2)$ are used to design the band stop structure. Choose $\text{G} = 1.5, \text{Z}_{0\text{e}} = 150\ \Omega, \text{Z}_{0\text{o}} = 100\Omega, \text{Z}_{3\text{A}} = 30\Omega$, and $\theta_{3\text{A}} = 54°$ at $f_{\text{c}} = 1.8$ GHz, which is $\theta_{3\text{A}} = 180°$ at $f_0 = 6$ GHz.

The physical length of $\theta_{3\text{A}}$ is a little shorter due to the embedded band-stop structure. It becomes $\theta_{3\text{A}} = 155°$ instead of $\theta_{3\text{A}} = 180°$ at $f_0 = 6$ GHz based on simulation. To simplify the design, choose $\text{Z}_{3\text{B}} = \text{Z}_1 = 110\ \Omega$, and, then, $\theta_{3\text{B}} = 35°, \theta_4 = 60°$, and $\theta_3 = 225°$ are derived from (3)–(5).

The final layout, dimensions, and realization of the proposed LPF are shown in Fig. 4. The frequency response is shown in Fig. 5. The rejection band with embedded band-stop structure has been extended from 2.25 GHz to 7.26 GHz when dB $(\text{S}_{11}) < -10$, whereas the rejection band of the original step-impedance LPF is from 2.25 GHz to 4.76 GHz. The simulated



(a)



(b)

Fig. 4. Physical dimensions and photo of the proposed LPF.

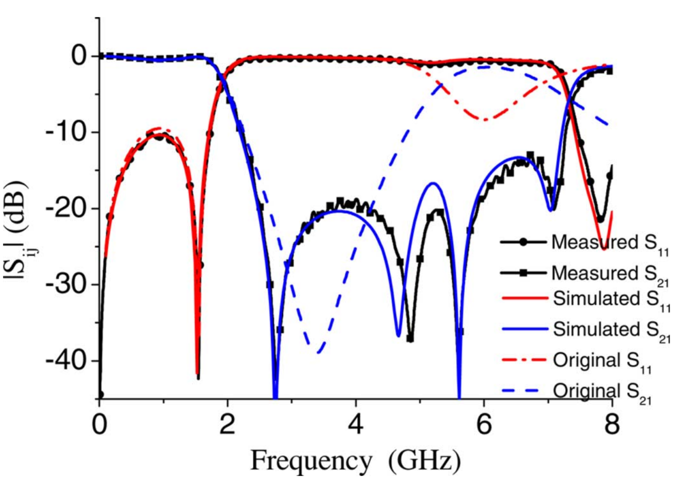


Fig. 5. S-parameters of the novel wide rejection band LPF.

S-parameters and the measured results of the proposed LPF agree well with each other, as shown in Fig. 5. The cut off frequency and the pass-band ripple of the proposed remain unchanged.

IV. Conclusion

A novel microstrip LPF with an embedded band-stop structure is presented in this letter. With a wide band-stop structure constructed from a band-stop filter, an ultra-wide rejection band of the classic step-impedance LPF is achieved. The LPF and the band-stop structure are designed at two separate frequencies, but share the same layout. The results show the rejection band becomes much wider, which covers from 2.25 GHz up to 7.26 GHz.

This dual-frequency design process can be applied to miniaturized microstrip LPFs to improve their performance. Moreover, it is a generic method suitable to promote the frequency response of step-impedance microstrip LPFs, while the cut-off frequency is not shifted and the physical dimension is unchanged.

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