Compact Microstrip Low-Pass Filter With Sharp Rejection

Wen-Hua Tu, *Student Member, IEEE,* and Kai Chang, *Fellow, IEEE*

***Abstract*—This letter presents a compact multisection sharp-rejection microstrip low-pass filter. Each section is consisted of a microstrip line section and an interdigital capacitor. The analysis for optimizing the attenuation poles by adjusting the finger number, and the width and length of the microstrip line section is presented. The cascaded four-section low-pass filter has a return loss of better than 17 dB and an insertion loss of less than 0.7 dB from dc to 1.6 GHz. The rejection is better than 20 dB from 2.1 to 7.5 GHz.**

***Index Terms*—Interdigital capacitor, low-pass filter, sharp rejection.**

I. Introduction

LOW-PASS filters have been widely used to suppress harmonics and spurious signals. The conventional stepped-impedance filters, however, can only provide a gradual cutoff frequency response [1]. In order to achieve a sharp cutoff frequency response, more sections are needed, but increasing sections will also increase the loss in the passband and circuit size. Recently, semi-lumped low-pass filters [2] are reported with a sharp cutoff frequency response, unfortunately, soldering lumped components will increase fabrication difficulties and manufacturing repeatability is difficult to maintain. Low-pass filters using coupled lines [3] or stepped-impedance hairpin resonators [4] have finite attenuation poles in cutoff frequency band. However, because the capacitance of the coupled lines is too small, the finite attenuation pole cannot be located close to the passband. Consequently, the cutoff frequency response is gradual.

In this letter, a compact multisection sharp-rejection microstrip low-pass filter with each section using a microstrip line section and an interdigital capacitor is presented. Without the two wide low-impedance lines used in [5], the presented filter has the advantages of compact size and ease of cascading. Because no lumped component is used, these planar filters are easy to fabricate. In addition, since the interdigital capacitors can provide a bigger capacitance, the finite attenuation pole can be located closer to the passband, thus achieves a sharp cutoff frequency response. The analysis method that is based on transmission-line model for optimizing the attenuation poles is also presented and is used to design a cascaded low-pass filter with a wide cutoff frequency response.

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The authors are with the Department of Electrical Engineering, Texas A&M University, College Station, TX 77843-3128 USA (e-mail: chang@ee.tamu.edu).

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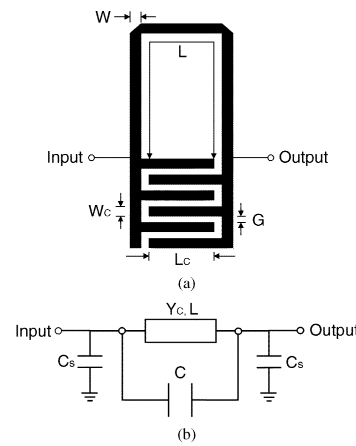

Fig. 1. Low-pass filter (a) schematic and (b) equivalent circuit model.

II. Attenuation Pole Analysis

Fig. 1 shows the configurations of the proposed low-pass filter and the equivalent circuit, where C_s is the sum of the capacitance to the ground of the junction and the interdigital capacitor. For the ease of analytical analysis, the C_s is neglected, and the S_{21} of the proposed filter can be derived using ABCD-, Y-, and S-parameters calculation given by [2]

$$S_{21} = \frac{j2Y_0(\omega C - Y_c \csc(\beta L))}{\Delta Y} \quad (1)$$

with

$$\Delta Y = Y_0^2 + Y_c^2 + j2Y_0(\omega C - Y_c \cot(\beta L)) + \omega C Y_c(\cot(\beta L) - \csc(\beta L))$$

where Y_0 is the input and output microstrip line characteristic admittance, Y_c is the characteristic admittance of the upper microstrip line, β is the propagation constant, ω is the angular frequency, and C is the equivalent capacitance of the interdigital capacitor. The attenuation poles can be found by setting $S_{21} = 0$, namely

$$\omega C = Y_c \csc(\beta L). \quad (2)$$

Therefore, when the left and right sides of (2) are plotted versus frequency, the intersections of the two curves determine the frequencies of the attenuation poles. Inspecting (2), the frequencies of the attenuation poles can be fixed by selecting the finger number of the interdigital capacitor (C), the length of the upper microstrip line section (L), and the width (W) or the characteristic impedance (Y_c).

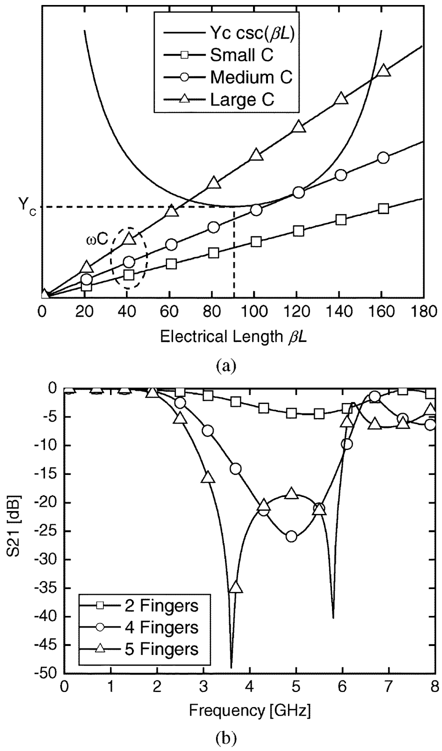

Fig. 2. Filters with 2-, 4-, and 5-finger interdigital capacitors. (a) Pictorial descriptions and (b) simulated insertion loss with the following parameters: $L =$ 10.12 mm, $W = W_C =$ 0.3 mm, $G =$ 0.2 mm, and $L_C =$ 1.78 mm.

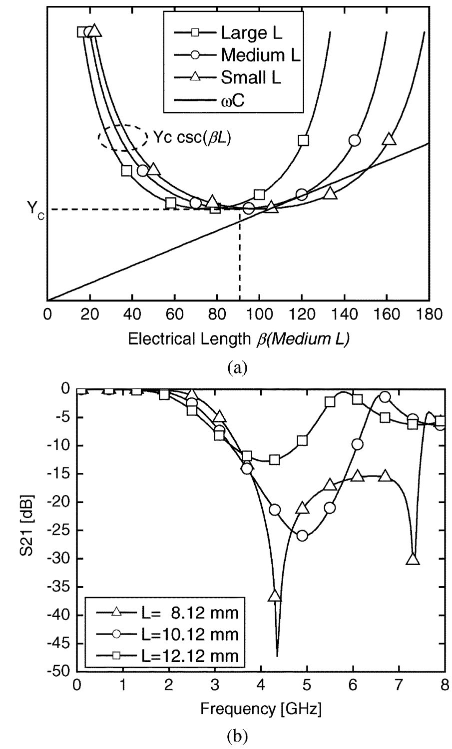

Fig. 3. Filters with different line lengths. (a) Pictorial descriptions and (b) simulated insertion loss with the following parameters: four fingers, $W = W_C =$ 0.3 mm, $G =$ 0.2 mm, and $L_C =$ 1.78 mm.

Fig. 2(a) shows the pictorial descriptions of varying the capacitance C. When C is large, there are two intersections (i.e., two attenuation poles). At certain medium value of C, the two intersections become one intersection and only one attenuation pole is obtained. Further decreasing capacitance C will produce no intersection and no attenuation pole is obtained. To verify this concept and take the discontinuities into account, a full-wave electromagnetic simulator IE3D [6] is used to calculate the frequency response of the low-pass filters with two-, four-, and five-finger interdigital capacitors (i.e., different capacitance values of C). All the filters are built on 25-mil RT/Duroid 6010.8 ($\varepsilon_r = 10.8$) substrates. The simulated results as showed in Fig. 2(b) predict the change of attenuation poles well. Because the capacitor with five fingers provides a large capacitance C, the filter with the five-finger capacitor shows two attenuation poles at 3.6 and 5.8 GHz. The filter with a four-finger capacitor (medium C) has only one attenuation pole at 4.9 GHz, and the filter with a two-finger capacitor (small C) does not have any attenuation pole.

Fig. 3(a) shows the pictorial descriptions of varying the microstrip line length L. Given a capacitance C and a characteristic admittance Y_c, decreasing or increasing L will expand or shrink $Y_c \csc(\beta L)$, respectively, and two intersections or no intersection will be obtained. Fig. 3(b) shows the simulated insertion loss of the filters with 8.12, 10.12, and 12.12 mm long microstrip line sections. The filter with $L =$8.12 mm has two attenuation poles at 4.35, and 7.3 GHz. On the other hand, for $L =$12.12 mm, no attenuation pole is observed.

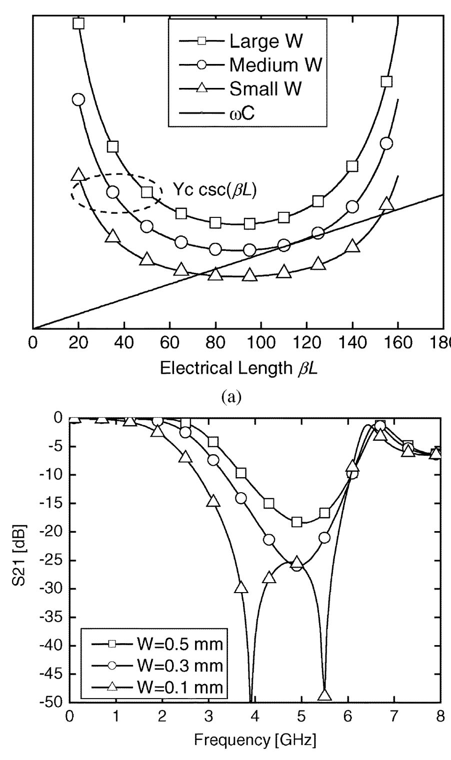

Fig. 4. Filters with different line widths. (a) Pictorial descriptions and (b) simulated insertion loss with the following parameters. $L =$ 10.12 mm, four fingers, $W_C =$ 0.3 mm, $G =$ 0.2 mm, and $L_C =$ 1.78 mm.

Fig. 4(a) shows the pictorial descriptions of the filters with different microstrip line widths that determine the characteristic admittance Y_c. Since the characteristic admittance Y_c of the microstrip line decreases as its line width decreases, the local min-

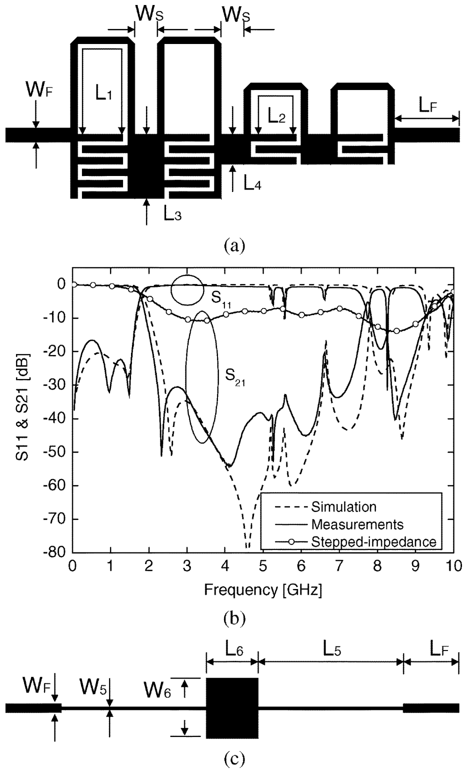

Fig. 5. (a) Schematic of cascaded four-section low-pass filter, (b) simulated and measured results, and (c) stepped-impedance low-pass filter. $L_1 = 10.12$ mm, $L_2 = 6.12$ mm, $L_3 = 2.8$ mm, $L_4 = 1.3$ mm, $L_5 = 9.8$ mm, $L_6 = 3.5$ mm, $W_s = 1$ mm, $W = W_C = 0.3$ mm, $W_5 = 0.2$ mm, $W_6 = 4$ mm, $W_f = 0.57$ mm, $G = 0.2$ mm, $L_C = 1.78$ mm, and $L_f = 15$ mm (L_f was arbitrarily chosen for convenience).

imum value of $Y_c \csc(\beta L)$ decreases accordingly. Therefore, two intersections (two attenuation poles) are obtained for a small line width and there is no attenuation pole for a large line width. Fig. 4(b) shows the simulated insertion loss of the filters with different lines widths of 0.1, 0.3, and 0.5 mm. The filter with the line width of 0.1 mm has two attenuation poles at 3.9, and 5.5 GHz, while the filter with the line width of 0.5 mm does not have any sharp attenuation pole.

In summary, varying the capacitance C is the most effective way to control the attenuation poles. Nevertheless, for the application to suppress the specific harmonics and spurious signals, varying the microstrip line length L and the characteristic admittance Y_c gives more freedom to control the attenuation poles.

III. Low-Pass Filter With Wideband Rejection

The analysis method discussed in Section II is used to design a low-pass filter with a wide cutoff frequency band. Fig. 5 shows the schematic and results of the four-section cascaded low-pass filter. The first two identical sections are designed to have two attenuation poles at 2.5 and 4.8 GHz, and the last two identical sections are designed to have two attenuation poles at 5.1 and 6.9 GHz for a wide-band cutoff frequency response. The simulated results are obtained by IE3D [6]. The filter has a 3-dB passband ranged from dc to 1.7 GHz. From dc to 1.6 GHz, the insertion loss is less than 0.7 dB and the return loss is better than 17 dB. The rejection is greater than 20 dB from 2.1 to 7.5 GHz. On the other hand, a five-pole Chebyshev low-pass filter with the cutoff frequency $f_C = 1.5$ GHz and passband ripple of 0.1 dB (i.e., return loss better than 16.42 dB) can be used to meet the same performance of the proposed filter. This conventional stepped-impedance filter, however, requires a 99-Ω microstrip line (i.e., line width = 0.075 mm) to implement a distributed inductor. The narrow microstrip line is not only too narrow to fabricate but also will limit the current-carrying capability. The narrow line is also very lossy. Furthermore, although a stepped-impedance filter having a response with fewer than four poles can be implemented with the practical line widths, its cutoff frequency response is not as sharp as the proposed filter. Fig. 5(b) also shows the measured insertion loss of the three-pole Chebyshev stepped-impedance low-pass filter [Fig. 5(c)] with the cutoff frequency $f_C = 1.5$ GHz and passband ripple of 0.1 dB. The proposed four-section filter shows a much sharper cutoff frequency response than the stepped-impedance filter.

IV. Conclusion

A compact sharp-rejection microstrip low-pass filter is presented. The analysis for finding the attenuation poles is investigated. This analysis method is especially useful in low-pass filter design to suppress the specific harmonics and spurious frequencies. Applying the analysis method, a cascaded low-pass filter is designed, fabricated, and tested with an insertion loss of less than 0.7 dB and a return loss of better than 17 dB from dc to 1.6 GHz. The wide-band rejection is greater than 20 dB from 2.1 to 7.5 GHz.

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