Proceedings of Asia-Pacific Microwave Conference 2006

Compact Low-Pass Filter for Harmonics Suppression

Rui Li, Dong Il Kim, and Chang Mook Choi

Department of Radio Sciences and Engineering, Korea Maritime University
Dongsam-dong, Youngdo-ku, Busan, 606-791, Korea
Tel: +82-51-410-4932, Fax: +82-51-405-4256
Email: zcrlr@hotmail.com, dikim@mail.hhu.ac.kr, and nav-sun@hanmail.net

Abstract **— In this paper, a new compact low-pass filter with three finite attenuation poles at stopband is presented. The new structure is composed of a pair of symmetrical parallel coupled-line and a shunted capacitor. With this configuration, three finite attenuation poles can be available for 2nd, 3rd, and 4th harmonics suppression. The research method is based on transmission-line model for tuning the attenuation poles. In order to examine the feasibility of the proposed structure, a low-pass filter based on microstrip structure with harmonics suppression is designed, fabricated, and measured. The experimental results of the fabricated circuit agree well with the simulation and analytical ones.**

Index Terms **— Finite attenuation poles, harmonics suppression, low-pass filter, parallel coupled-line.**

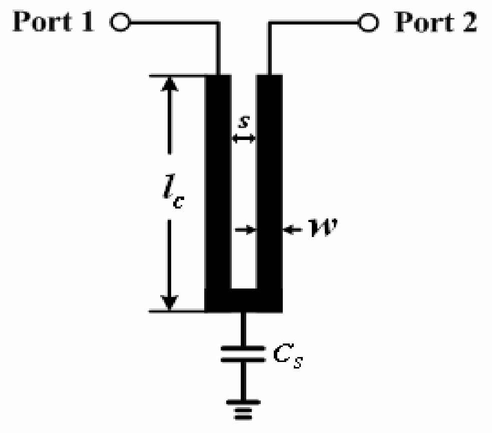


Fig. 1. Proposed compact low-pass filter.

I. INTRODUCTION

The low-pass filters are often employed in many communication systems to suppress harmonics and spurious signals, with the demand for compact size, low insertion loss, and high attenuation. The conventional low-pass filters, such as open-stub low-pass filters and stepped-impedance low-pass filters can not meet the requirements for modern communication systems because of their large size and narrow stopband. For sharp cutoff and high attenuation at stopband, the order of the stepped-impedance low-pass filter must be very high [1], [2], thereby the circuit size and insertion loss will be increased. In literature, many design approaches have been proposed to improve the low-pass filter's performance. The low-pass filters using PBG and DGS structures [3], [4] can improve the skirt characteristics and provide wide and deep stopband as compared with the conventional low-pass filters. A low-pass filter using multiple cascaded hairpin resonators that can provide a very sharp cutoff frequency response with low passband insertion loss was demonstrated in [5] and [6]. However, this type of design approach is a little complicated and just used to synthesize some parts of available prototype low-pass filters.

In this paper, a new compact low-pass filter with three finite attenuation poles at stopband is proposed. This new type of low-pass filter based on microstrip structure, which consists of a pair of symmetrical parallel coupled-line and a shunted capacitor, is designed. Compared with the conventional low-pass filter, the proposed one demonstrates some attractive features: simple structure, harmonics suppression, and sharp skirt characteristics.

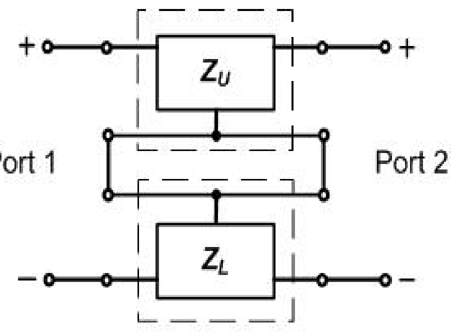
II. FINITE ATTENUATION POLES ANALYSIS

Fig. 1 shows the basic layout of the proposed compact low-pass filter. It consists of a shunted capacitor C_S and a pair of symmetrical parallel coupled-line with a length of l_C. Z_{oe} and Z_{oo} represent the even- and odd-mode characteristic impedances of the parallel coupled-line, respectively.

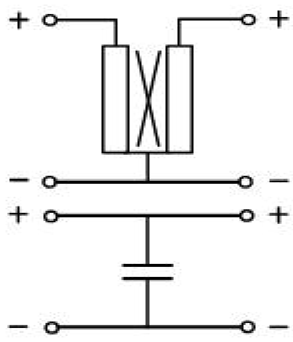
We assume that the structure is lossless and the width of the feeding lines is negligible. Under these assumptions, the proposed structure can be divided into two sections: one is shunted capacitor section and the other is symmetrical parallel coupled-line section with its far end shorted. As shown in Fig. 2(a), the total $\boldsymbol{Z}$-matrix of a serially connected network can be given by [2]

$$[\boldsymbol{Z}_T] = [\boldsymbol{Z}_U] + [\boldsymbol{Z}_L] \tag{1}$$

where $[\boldsymbol{Z}_U]$ and $[\boldsymbol{Z}_L]$ are the impedance matrices of the upper and lower network, respectively.



(a)



(b)

Fig. 2. (a) Serially connected two-port network. (b) Decomposition diagram of the proposed structure.

As depicted in Fig. 2(b), the coupled-line and shunted capacitor sections can be seen as the upper and lower networks, respectively. For the upper network, the elements of the impedance matrix $[\boldsymbol{Z_U}]$ can be calculated by using even-odd mode analysis method as followings:

$$\boldsymbol{Z}_{11}^{U} = \boldsymbol{j}(\boldsymbol{Z}_{oe}\tan\theta_e + \boldsymbol{Z}_{oo}\tan\theta_o)/2 \tag{2a}$$

$$\boldsymbol{Z}_{21}^{U} = \boldsymbol{j}(\boldsymbol{Z}_{oe}\tan\theta_e - \boldsymbol{Z}_{oo}\tan\theta_o)/2 \tag{2b}$$

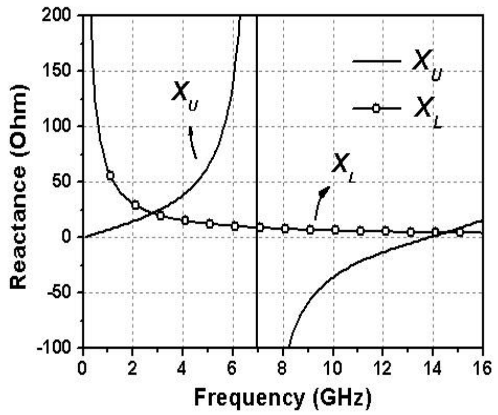
For the lower network, the elements of the impedance matrix are the same and can be derived as:

$$\boldsymbol{Z}_L = -\boldsymbol{j}/(\omega\boldsymbol{C}_S) \tag{3}$$

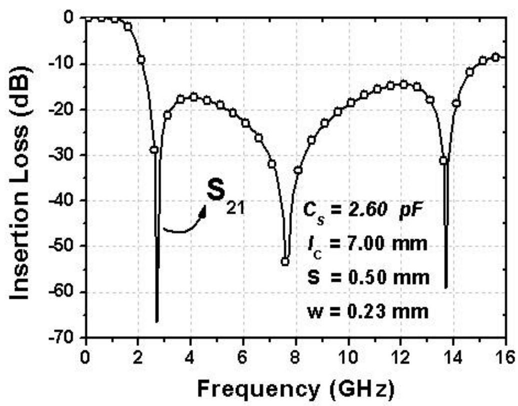
From the relationship between the impedance and scattering matrices, the transmission parameter of the network can be obtained by [7]

$$\boldsymbol{S}_{21} = \frac{2\boldsymbol{Z}_{12}^{T}\boldsymbol{Z}_0}{(\boldsymbol{Z}_{11}^{T}+\boldsymbol{Z}_0)(\boldsymbol{Z}_{22}^{T}+\boldsymbol{Z}_0)-\boldsymbol{Z}_{12}^{T}\boldsymbol{Z}_{21}^{T}} \tag{4}$$

where Z_0 is the characteristic impedance of the input and output microstrip line. The finite attenuation poles are located at the angular frequencies ω where $S_{21}(\omega) = 0$ or $Z_{21}(\omega) = 0$. Therefore, the frequencies of the finite attenuation poles should satisfy the following equation derived from (2b) and (3):



(a)

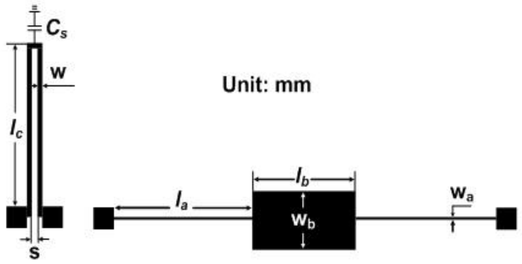


(b)

Fig. 3 Pictorial description of the locations of the finite attention poles. (a) Reactance description. (b) Simulated frequency responses with the following circuit parameters: C_S = 2.6 pF, l_C = 7.0 mm, s = 0.5 mm, and w = 0.23 mm.

$$(\boldsymbol{Z}_{oe}\tan\theta_e - \boldsymbol{Z}_{oo}\tan\theta_o)/2 = 1/\omega\boldsymbol{C}_S \tag{5}$$

Inspecting (5), the frequencies of the finite attenuation poles can be determined by the shunted capacitor C_S and the electrical parameters of the parallel coupled-line. Fig. (3a) shows the pictorial description of the upper and lower reactance as a function of frequency with specified electrical parameters of C_S= 2.6 pF, lc= 7.0 mm, s = 0.5 mm, and w = 0.23 mm. There are three intersections between the upper reactance function X_U and the lower one X_L over the stopband. It means that three finite attenuation poles will appear through the stopband at the same frequencies as the intersections between the upper and lower reactance functions. As illustrated in Fig. (3b), the predicted results are confirmed by the simulated frequency responses. The locations of the transmission zeros are almost same as those of the intersections shown in Fig. 3(a). Therefore, from this characteristic, we can predict and adjust the locations of the finite attenuation poles by changing the electrical parameters.

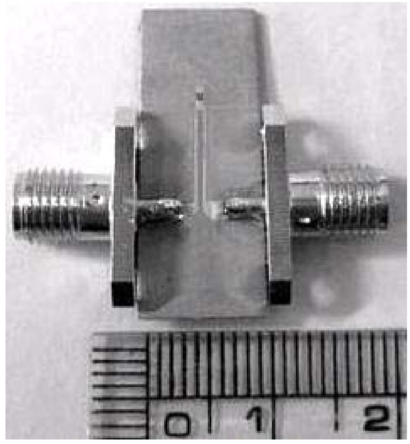


(a) (b)

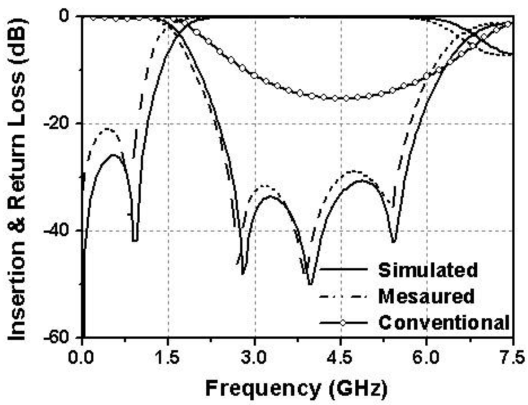
Fig. 4. Layouts of (a) the proposed low-pass filter and (b) conventional stepped-impedance low-pass filter.

TABLE I
COMPARISON OF THE PHYSICAL DIMENSIONS

Proposed LPF		**Stepped-impedance LPF**	
Coupled-line (mm)	Capacitor (pF)	High-Z line (mm)	Low-Z line (mm)
Length: 13	C_S : 1.5	Length: 11.51	Length: 8.45
Width: 0.4			
Space: 0.4		Width: 0.22	Width: 4.54
Substrate thickness: 0.76 mm, relative dielectric: 3.5			



(a)



(b)

Fig. 5 Proposed compact low-pass filter. (a) Photograph of the fabricated circuit. (b) Measured frequency responses compared with those of the simulated and conventional stepped-impedance low-pass filter.

III. LOW-PASS FILTER DESIGN FOR HARMONICS SUPPRESSION

By the above graphic analysis, the proposed compact low-pass filter can provide a wide rejection-band with three finite attenuation poles in it. This attractive feature can be used to improve harmonics and spurious suppression performance. To verify the proposed approach, a low-pass filter unit with its cutoff frequency at 1.3 GHz is developed. The electrical parameters of the parallel coupled-line and shunted capacitor are selected to suppress the 2nd, 3rd, and 4th harmonics, simultaneously. A compact low-pass filter is designed and fabricated on a 0.76-mm thick Taconic PCB with a relative dielectric constant of ε_r = 3.5. Adjusting the locations of the reactance intersection points by changing the circuit parameters, as well as optimized by Agilent ADS software, the circuit electrical parameters are determined as shown in Table I, and a comparison of the circuit physical dimensions between the proposed compact low-pass filter and the conventional stepped-impedance one has been made as illustrated in Fig. 4.

The fabricated low-pass filter was measured with Anritsu 37369D vector network analyzer. As shown in Fig. 5(b), the measured results agree well with the simulated ones. This low-pass filter has a 3-dB cutoff frequency at 1.3 GHz. The three finite attenuation poles at stopband are located at 2.7 GHz, 3.85 GHz, and 5.35 GHz with insertion losses of 46 dB, 47.9 dB, and 35.5 dB, respectively. The locations are almost same as the 2nd, 3rd, and 4th harmonics of the cutoff frequency. Thereby the harmonics can be eliminated effectively.

IV. CONCLUSIONS

A new compact low-pass filter with three finite attenuation poles at stopband has been developed in this paper. Through theoretical analysis and simulation performance, the rejection band can be controlled by adjusting the circuit electrical parameters. To verify the feasibility of the proposed method, a low-pass filter unit has been designed, fabricated, and measured. Based on our observations of simulation performance and measured results, this new type of low-pass filter demonstrates some desirable features compared with the conventional one, such as sharp skirt characteristics and harmonics and spurious suppression at stopband. In addition, the proposed approach can be further extended and used in high-order design process to achieve sharper skirt characteristics and a broad rejection band with much deeper attenuation level.

ACKNOWLEDGEMENT

This work was supported by the Korea Research Foundation Grant funded by the Korean Government (KRF-2005-005-J00502).

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