JOURNAL OF THE KOREAN INSTITUTE OF ELECTROMAGNETIC ENGINEERING AND SCIENCE, VOL. 11, NO. 2, JUN. 2011 JKIEES 2011-11-2-04

DOI : 10.5515/JKIEES.2011.11.2.090

Microstrip Bandpass Filter Using Stepped-Impedance Coupled-Line Hairpin Resonators with Enhanced Stopband Performance

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Abstract

In this paper, we propose a microstrip bandpass filter using stepped-impedance coupled-line hairpin resonators. The stepped-impedance coupled-line hairpin resonator has extended harmonic suppression in comparison with a conventional hairpin resonator due to transmission zero and the movement of harmonic frequencies resulting from the stepped-impedance characteristic. A high-pass type impedance/admittance inverter is employed in order to improve the lower frequency skirt characteristics of the passband. A 4-pole bandpass filter is designed and fabricated at 1.8 GHz. The measured results show the excellent attenuation performance at the stopband which is greater than 30 dB up to 10 GHz.

Key words : Coupled-Line, Enhanced Stopband Performance, Lumped-Element Circuit, Microstrip Bandpass Filter, Stepped-Impedance Hairpin Resonator.

Ⅰ. Introduction

A microwave filter is a two-port network used to control the frequency response at a certain point in microwave systems by providing transmission at frequencies within the passband of the filter and attenuation in the stopband of the filter [1]. Among the various types of microwave filters, bandpass filters play an increasingly important role because of the need to eliminate the noise in wireless communication systems, as a consequence of fragmented frequency [2]~[4].

A hairpin resonator is a very useful structure in the design of a microstrip bandpass filter. It shows the advantages of compact size, low cost, and easy fabrication. However, as a result of the distributed characteristic of the transmission line, undesired spurious responses are a problem for conventional hairpin filters and can seriously degrade their performance. Therefore, it is necessary to enhance the harmonic suppression characteristic and many studies have been conducted to achieve this target [5]~[10].

In this paper, a microstrip bandpass filter using steppedmpedance coupled-line hairpin resonators is proposed. The hairpin resonator used has a stepped-impedance configuration and a coupled-line section with its arms. This resonator exhibits wider stopband performance than conventional SIR. Furthermore, it has been used in the design of lowpass filters and offers enhanced stopband performance [11], [12]. Hence, in this paper, the equivalent circuit of the proposed resonator introduced in [12] is used to design the resonator and explain wide stopband characteristic. In addition, the inverters of both J_{12} and J_{34} in the fabricated 4-pole bandpass filter are realized by using a lumped-element high-pass type pi-network for enhancing the lower frequency skirt characteristics. In order to verify the proposed design, a 4-pole bandpass filter was designed and fabricated with a center frequency of 1.8 GHz. The measured results are in good agreement with the simulated ones, and show enhanced harmonic suppression performance compared with a conventional hairpin bandpass filter.

Ⅱ. Analysis of Proposed Filter

2-1 Stepped-Impedance Coupled-Line Hairpin Resonator with a Lowpass Characteristic

Fig. 1 shows the stepped-impedance coupled-line hairpin resonator with a lowpass characteristic, which consists of a transmission line and a coupled-line with electrical lengths of $Ø_2$ and $Ø_1$, respectively. Fig. 2 shows the equivalent circuit and parameters for the proposed resonator in Fig. 1 [12], [13]. The equivalent circuit parameters can be expressed as follows:

$$jB_a = j(1/Z_{0e})\tan\phi_1 \tag{1}$$

$$jB_b = j\frac{Z_{0e}-Z_{0o}}{2Z_{0e}Z_{0o}}\tan\phi_1 \tag{2}$$

Manuscript received January 5, 2011 ; revised April 20, 2011. (ID No. 20110105-001J)

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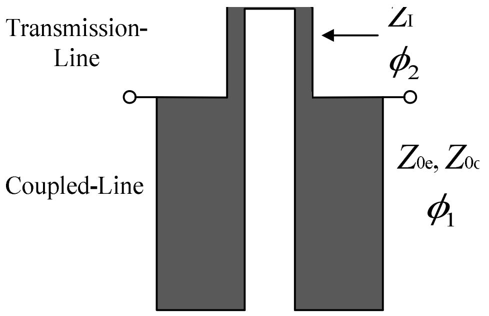


Fig. 1. Stepped-impedance coupled-line hairpin resonator with a lowpass characteristic.

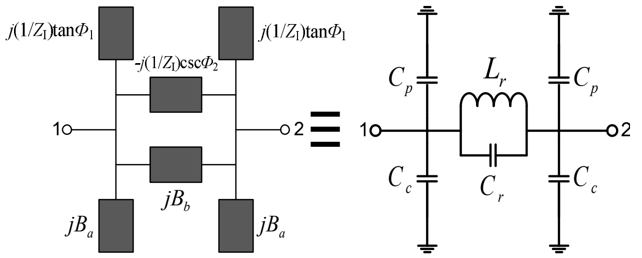


Fig. 2. The equivalent circuit for the proposed resonator in Fig. 1.

where Z_{0e} and Z_{0o} are even- and odd-mode impedances of the coupled-line, respectively. The design parameters for the resonator in Fig. 1 can be extracted by controlling (1) and (2).

When the circuit in Fig. 1 is directly connected to ports without coupling capacitors, the stepped-impedance hairpin-shaped circuit has the lowpass filter response as shown in Fig. 3.

On the other hand, when the coupling capacitor is used at the IN/OUT ports for the circuits in Fig. 1 and Fig. 2, the resonances in the resonator can be shown. Fig. 4 illustrates the simulated frequency responses of the stepped-impedance coupled-line hairpin resonator in Fig. 1 and its equivalent circuit in Fig. 2. As shown in Fig. 4, the proposed structure has a good stopband performance due to the transmission zero created by the parallel resonator (L_r, C_r) in Fig. 2, and the movement of harmonic frequencies resulting from the stepped-impedance characteristic.

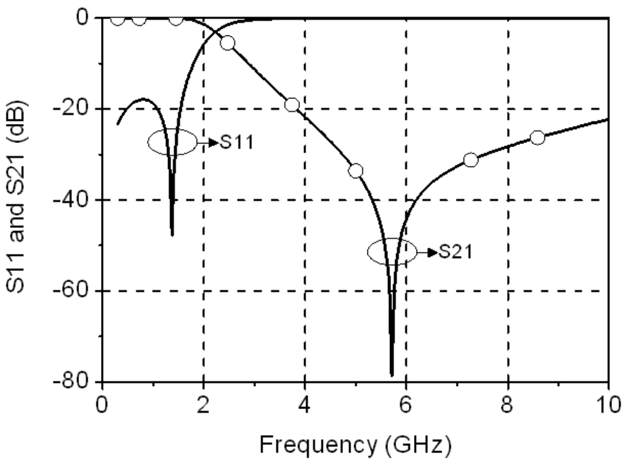


Fig. 3. Simulated frequency responses as a lowpass filter in Fig. 1 (Z_{0e}=21.5 Ω, Z_{0o}=10.1 Ω, Z_I=110 Ω, Φ_1=31° and Φ_2=15°).

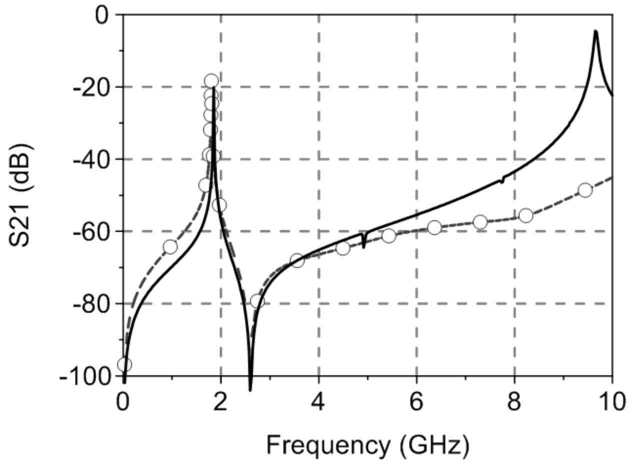


Fig. 4. Simulated frequency responses of the proposed hairpin resonator in Fig. 1 (circle symbol line) and its equivalent circuit in Fig. 2 (solid line). (Z_{0e}=21.5 Ω, Z_{0o}=10.1 Ω, Z_I=110 Ω, Φ_1=31° and Φ_2=15°).

As illustrated in Fig. 5, the structure of the proposed hairpin resonator is compared with those of the conventional and simple stepped-impedance hairpin resonators to confirm the improved stopband performance. The simulated results given in Fig. 6 show the different stopband performances of each structure in Fig. 5. The parameters for each type of resonator in Fig. 5 are as follows: (a) Z_0=70.8 Ω, Φ=184°, (b) Z_1=20.1 Ω, Z_2= 115.8 Ω, Φ_1=27.8°, Φ_2=30.9°, (c) Z_{0e}=21.5 Ω, Z_{0o}=10.1 Ω, Z_I=110 Ω, Φ_1=31°, and Φ_2=15°. Obviously, the conventional structure has several harmonic resonances at

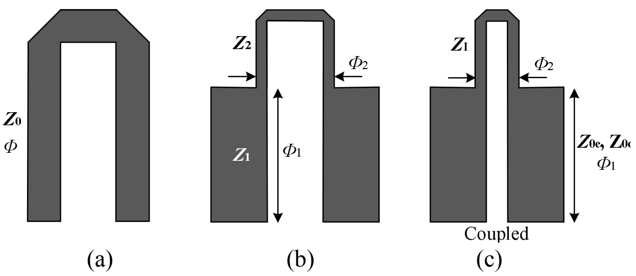


Fig. 5. (a) Conventional hairpin resonator. (b) Simple stepped-impedance hairpin resonator. (c) Proposed stepped-impedance hairpin resonator with a tight gap in the coupled-section.

high frequencies, while the simple stepped-impedance hairpin resonator shows only two resonance points in the range of up to 10 GHz [11].

However, the structure using the stepped-impedance coupled-line in Fig. 5(c) has only one resonance up to 10 GHz, and has a transmission zero. Therefore, this structure has excellent stopband performance compared to both the conventional and simple stepped-impedance structures.

2-2 Highpass Type Lumped-Element Admittance Inverter

The resonator in Fig. 1 follows the lowpass filter characteristic, so that the lower stopband characteristic is not satisfactory. For improving the lower stopband characteristic, the highpass type lumped-element circuit in Fig. 7 is utilized as the admittance inverter.

As is well known, the quarter-wavelength transmission line, which is an admittance inverter in common use, can be made equivalent to the lumped-element circuit consisting of two shunt inductors and one series capacitor as shown in Fig. 7. The highpass characteristic of this inverter can make the enhanced lower frequency skirt characteristic. The relation between the characteristic admittance (Y_0) and the series capacitance (C) in Fig. 7 is of the form as follows.

$$C=\frac{Y_0}{\omega},\qquad L=\frac{1}{\omega Y_0}. \tag{3}$$

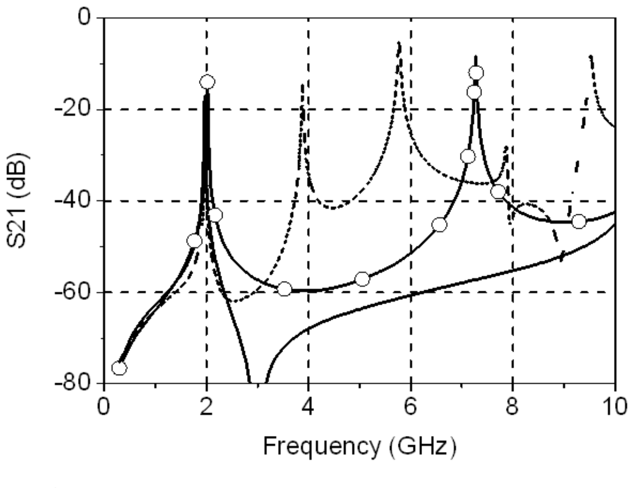


Fig. 6. Simulated frequency responses of the conventional (dotted line), simple stepped-impedance (circle symbol line), and proposed (solid line) structures.

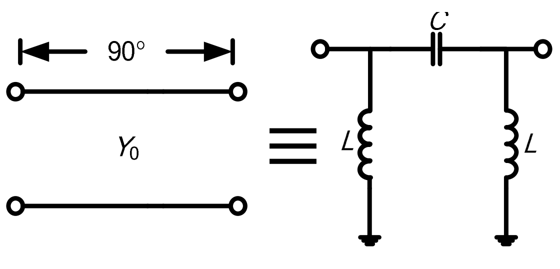


Fig. 7. The equivalent lumped-element circuit of the quarter-wavelength transmission line.

Ⅲ. Design Procedure

The proposed microstrip bandpass filter using stepped-impedance coupled-line hairpin resonators is designed at the center frequency of 1.8 GHz with a 0.01 dB ripple level of the Chebyshev prototype. Fig. 8 shows the proposed 4-pole bandpass filter, which consists of the stepped-impedance coupled-line hairpin resonators and the chip-capacitors (C). Firstly, design parameters for each resonator in Fig. 8 can be obtained according to [12]. These parameters are as follows: Z_{0e}=21.5 Ω, Z_{0o}=10.1 Ω, Z_1=110 Ω, Φ_1=31° and Φ_2=15°. For the J-inverter between the first and the second resonators, the capacitance (C) in Fig. 8 can be derived using (3). The inductance (L) in Fig. 7 is absorbed into the lengths of the respective resonators in Fig. 8. The coupling coefficient between the second and third resonators in Fig. 8 is derived as 0.04 according to [14], so that the gap (s_3) between the second and third resonators in Fig. 8 becomes 0.3 mm in order to achieve the coupling coefficient using advanced design system (ADS) 2008 momentum. Moreover, the shape of the first and last resonators is modified due to the fine adjustment for the required external quality factor value. As a consequence, the physical dimensions of the proposed filter are as

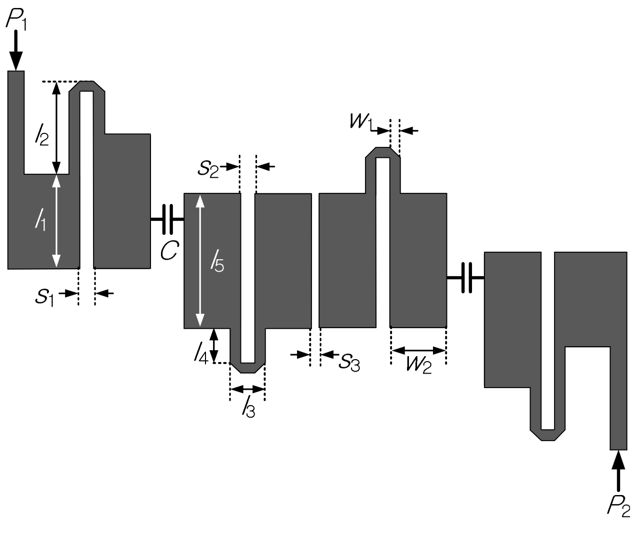
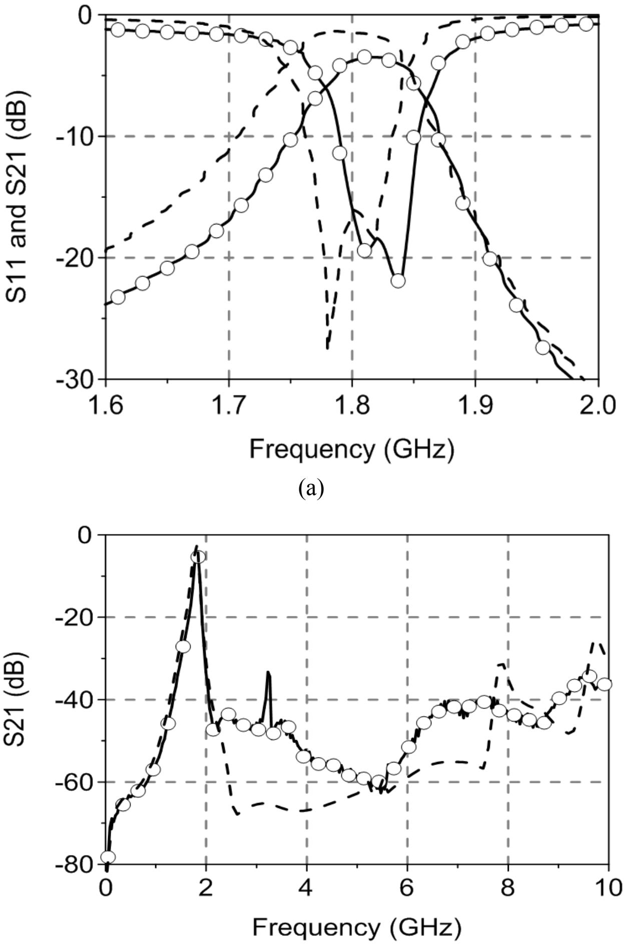


Fig. 8. Layout of the proposed microstrip bandpass filter using stepped-impedance coupled-line hairpin resonators with enhanced stopband performance.

follows: w_1=0.5 mm, w_2=6.4 mm, l_1=9.5 mm, l_2=6.5 mm, l_3=1.3 mm, l_4=1.0 mm, l_5=17.5 mm, s_1=0.3 mm, s_2=0.3 mm, s_3=0.3 mm, and C=1 pF.

Ⅳ. Simulation and Measurement Results

This proposed microstrip bandpass filter has been fabricated using the substrate Rogers RO3003 with a thickness of 30 mil (0.75 mm) and a relative dielectric constant of 3.0. The measured frequency responses of the fabricated filter are illustrated in Fig. 9, together with the responses from the EM simulation using ADS 2008 Momentum. A photograph of the fabricated bandpass filter is presented in Fig. 10. The measured insertion loss and return loss of the passband are 3.5 dB and 15 dB, respectively and the measured bandwidth is approximately 65 MHz. The measured passband characteristic depicted in Fig. 9 has little difference with the simulated one because the value of the lumped capacitors, which act as inverters, is slightly different to the ideal capacitance. The out-of-band rejection is better than 30 dB up to 10 GHz in measurement.



(a)

(b)

Fig. 9. (a) The simulated and measured narrow band performances, and (b) Wide band performances. Simulated results (dotted line) and measured results (circle symbol line).

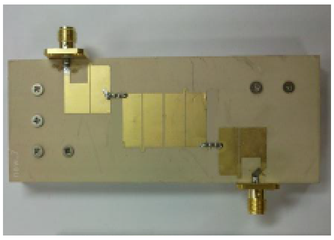


Fig. 10. Photograph of the fabricated bandpass filter. The overall size of the filter is 6.5×3.5 cm^2.

Ⅴ. Conclusion

In this paper, we proposed a microstrip bandpass filter with excellent stopband performance. To enhance spurious performance, we employed a stepped-impedance coupled-line hairpin resonator, which has wide stopband performance. Moreover, lumped-element inverters improve the lower frequency skirt characteristic of the proposed bandpass filter. The proposed bandpass filter has been fabricated for experimental demonstration. The measured and simulated results show good agreement, which demonstrates the great application potential of the proposed filter.

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