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Design of compact low pass filter with wide stop band using tri-section stepped impedance resonator

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ABSTRACT

This paper reports the design of a compact low pass filter (LPF) with wide stop band region using tri-section stepped impedance resonators in microstrip medium. Experimental results of a low pass filter designed at 1 GHz have been compared against the analytical and EM simulation results for the validation of the design. Results are satisfactorily matching each other. The maximum insertion of the measured filter is 0.2 dB and minimum return loss is 13.5 dB over the pass band. The stop band rejection is better than 20 dB from 1.5 GHz to 4.2 GHz and hence wide stop band performance is achieved. Overall size of the filter is 30 mm × 20 mm × 0.78 mm which is 0.1λ × 0.066λ × 0.0026λ at 1 GHz.

1. Introduction

Microstrip low pass filters with wide stop band are one of the key elements in modern wireless systems to reject the unwanted high frequency components. Though conventional transmission line low pass filter using open stubs has salient features such as simple structure and easy synthesis procedure, it has narrow upper stop bandwidth which limits the system performance [1]. This is due to the frequency distributed behavior of lines and stubs. Various approaches have been reported in the literature to achieve wide stop band region in low pass filters [1–8]. In [2], microstrip stepped impedance hairpin resonators are used to design compact low pass filter with wide rejection bandwidth. Coupled line hairpin units are proposed to design stop band expanded low pass filter in [3]. In [4–8], different types of defected ground structures are used to design low pass filter with wide stop band. The stop band region is determined from the shape of the slot over the ground. Single cell or slot suppresses one harmonic, the second and third harmonics can be suppressed by using cascaded configurations of several basic cells. But cascade of cells increases the size and insertion loss of the filter.

In this paper, tri-section stepped impedance resonator (SIR) is used to design compact low pass filter with wide stop band and this tri-section SIR is folded to achieve miniaturization. Fig. 1 shows the tri-section SIR consisting of three different sections with impedances Z_1, Z_2 and Z_3 respectively. Impedance sections are playing vital role in locating the spurious frequency of the filter. Section 2 describes the design and realization of such a tri-section SIR low pass filter. Experimental results of 1 GHz low pass filter are validated against the analytical and EM simulation results in Section 3. Section 4 concludes this paper.

2. Design of low pass filter

A low pass filter with 1 GHz cut off frequency is designed using tri-section SIR. Structural parameters of microstrip medium used for the present filter design are listed in Table 1. The cut off frequency of low pass filter having symmetrical tri-section SIR and equal section lengths can be derived as [9]

$$\theta = \tan^{-1}\left(\sqrt{\frac{K_1K_2}{K_1+K_2+1}}\right) \quad (1)$$

where $K_1 = Z_3/Z_2$ and $K_2 = Z_2/Z_1$. Resonator's total electrical length at the low pass cut off frequency is given by

$$\theta_T = 6\theta = 6\tan^{-1}\sqrt{\frac{K_1K_2}{K_1+K_2+1}} \quad (2)$$

The first spurious 'f_{s1}' (second pass band) of low pass filter occurs at

$$f_{s1} = \frac{\theta_{s1}}{\theta}f_o \quad (3)$$

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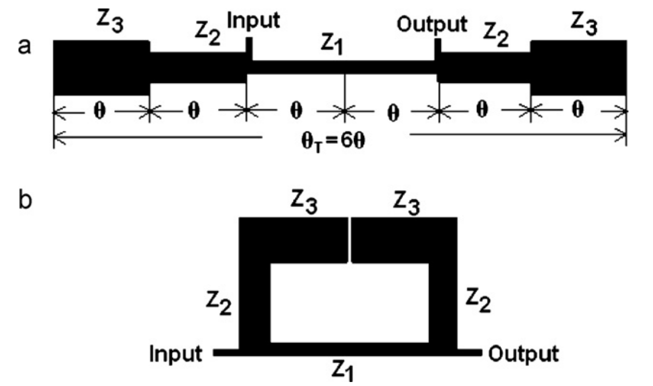

Fig. 1. Proposed low pass filter using tri-section SIR. (a) Straight resonator and (b) folded resonator design of low pass filter.

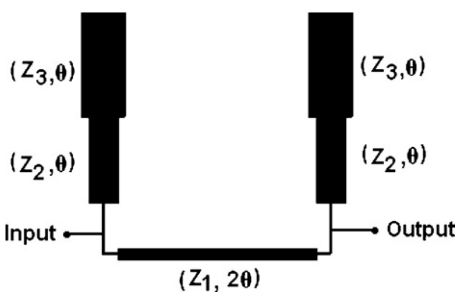

Fig. 2. Equivalent circuit of low pass filter.

where

$$\theta_{s1} = \tan^{-1}\sqrt{\frac{(K_1+1)^2(K_2+1)+K_2^2K_1}{K_2^2+K_1K_2+K_2}}$$

Fig. 2 shows the low pass filter in terms on transmission lines and open circuit stubs. The overall ABCD matrix of the low pass filter is given below:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & \dfrac{jZ_2(\tan\theta - K_1\cot\theta)}{1+K_1} \\ 0 & 1 \end{bmatrix} \times \begin{bmatrix} \cos 2\theta & jZ_1 \sin 2\theta \\ \dfrac{j\sin 2\theta}{Z_1} & \cos 2\theta \end{bmatrix} \times \begin{bmatrix} 1 & \dfrac{jZ_2(\tan\theta - K_1\cot\theta)}{1+K_1} \\ 0 & 1 \end{bmatrix} \qquad (4)$$

The impedance ratios K_1 and K_2 are chosen to be 0.96 and 0.17 respectively to move the second pass band to $4.8f_o$ (4.8 GHz). The values of the impedances chosen for the design are $Z_1 = 176\,\Omega$, $Z_2 = 30\,\Omega$ and $Z_3 = 29\,\Omega$ and widths are 0.14 mm, 4.9 mm and 5.1 mm respectively. The total resonator length is 92.8°. Length of each unfolded resonator calculated from Eq. (2) was 56.1 mm ($6\theta = 92.8°$). ABCD matrix of individual filter sections (lines and stubs) is cascaded to find the overall scattering matrix of the filter. The discontinuity effects of junctions, steps and gap were taken care in the calculation. Fig. 3 shows scattering parameters of low pass filter obtained from the analytical results (calculated using MATLAB) for various values of impedance ratios. Comparison of low pass filter using tri-section SIR and two-section SIR is shown in Fig. 4. Impedance ratio 'K' of two-section SIR LPF is 0.163 (Z_3/Z_1) and total electrical length of resonator is 88° [10]. Tri-section SIR low pass filter has wide stop band region than two-section SIR low pass filter and sharp rejection characteristics are observed in the filter.

Table 1
Structural parameters of microstrip.

Parameters	Values
Substrate thickness 'h'	0.78 mm
Substrate permittivity 'ε_r'	2.17
Loss tangent	0.0009

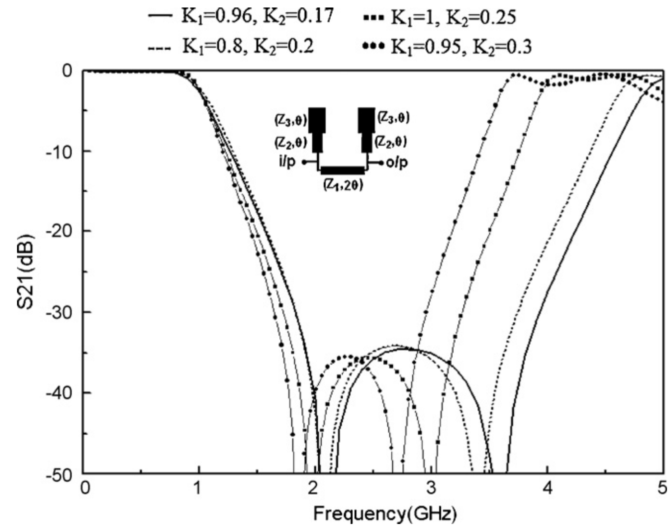

Fig. 3. Analytical results of tri-section SIR low pass filter.

3. Experimental results

Fig. 5 shows the photograph of fabricated compact low pass filter. The filter was fabricated using standard printed circuit board prototyping process. The performance of the filter was measured using vector network analyzer. Fig. 6 compares the experimental scattering parameters of the low pass filter against the analytical calculations and EM simulation results [11]. Results are satisfactorily matching each other. Results show that maximum insertion loss is 0.2 dB and stop band attenuation is better than 20 dB from 1.5 GHz to 4.2 GHz. The second pass band of the filter is moved to 4.8 GHz. Overall size of the compact low pass filter is 30 mm × 19 mm which is 0.1λ × 0.066λ, whereas the low pass fil-

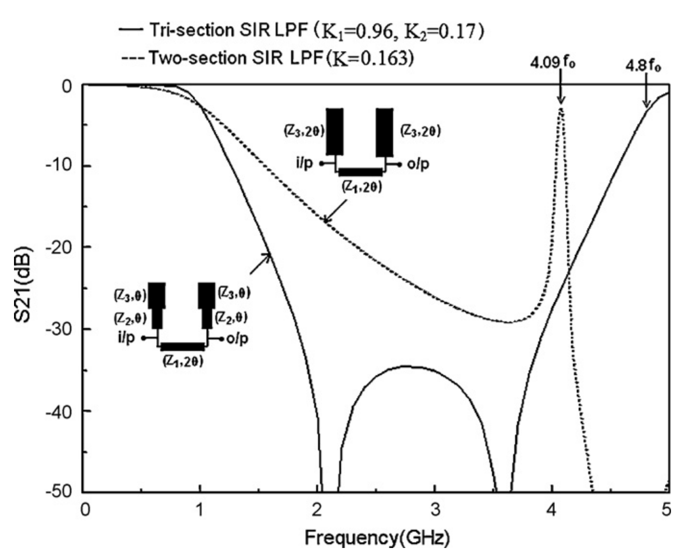

Fig. 4. Comparison of low pass filter using proposed tri-section SIR and two-section SIR.

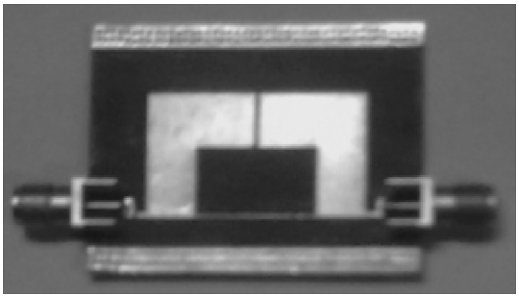

Fig. 5. Assembled low pass filter.

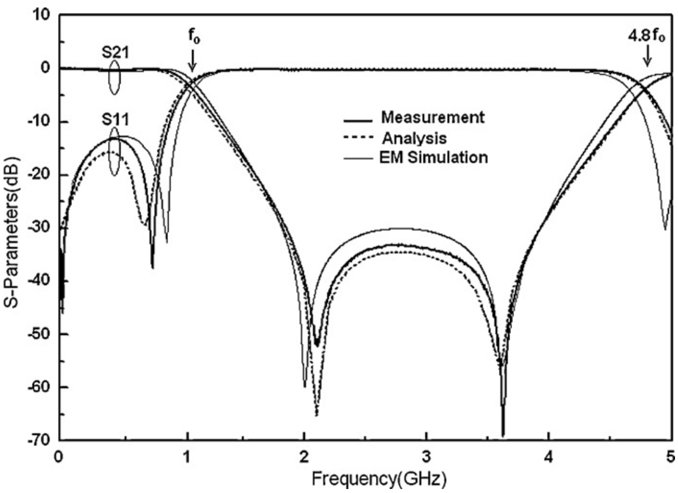

Fig. 6. Comparison of analytical, simulated and measured scattering parameters of low pass filter.

ter using U-shaped defected ground structure occupies the space of $0.56\lambda \times 0.104\lambda$ [8]. This filter also occupies 40% reduced area compared to a conventional low pass filter using stubs of the same order [1].

4. Conclusions

In this paper, a compact low-pass filter has been proposed using tri-section stepped impedance resonator. The filter has shown a wide stop band bandwidth. The wide stop band has been achieved by properly choosing the impedances of the resonator. The measured results of 1 GHz low pass filter are presented and are in good agreement with the analytical and simulation results. Stop band rejection is better than 20 dB from 1.5 GHz to 4.2 GHz.

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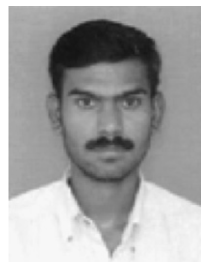

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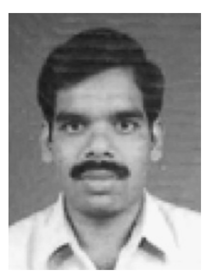

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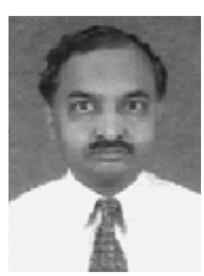

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