Microstrip Lowpass Filter with Very Sharp Transition Band Using T-Shaped, Patch, and Stepped Impedance Resonators

Mohsen Hayati and Akram Sheikhi

A compact microstrip lowpass filter (LPF) with an elliptic function response is proposed. A high equivalent capacitance and inductance between the structures of the resonator result in the sharp transition band of 0.04 GHz from 4 GHz to 4.04 GHz with an attenuation level of –3 dB and –20 dB, respectively. To improve the LPF rejection band, multiple open stubs are connected to the proposed resonator. A filter with a 3-dB cut-off frequency at 4 GHz is designed, fabricated, and measured, and agreement between the measured and simulated results is achieved. The results show that a stopband bandwidth of 131% with a suppression level better than –20 dB is obtained while achieving a compact size with a wide stopband.

Keywords: Patch, lowpass filter, microstrip, stepped impedance resonator, transition band.

I. Introduction

High performing compact lowpass filters (LPFs) with wide stopbands are in high demand for many wireless communication systems to suppress noise and spurious signals. Conventional filters with open stubs and stepped impedance structures suffer from a gradual cut-off frequency and narrow stopband bandwidth [1], [2]. As such, several methods have been proposed to implement LPFs [3]-[9]. The ground structure used in [3], [4] to obtain a wide stopband requires minimal air space beneath the ground plane owing to etching in the ground plane and therefore must be suspended, which leads to an increased filter size. An effective way to reach a wide stopband is to cascade the multiple cells with the different dimensions, as shown in [5], [6], but this method increases the size of the filter. One of the important factors in LPFs is a sharp transition band. An LPF with a wide stopband was presented in [7], [8], but the response of the transition band was not sharp enough. To achieve a sharp response, we must enhance the equivalent capacitance and inductance in the structure of the proposed resonator. The researchers in [9] achieved a sharp response with high equivalent capacitance and inductance created in the structure of the proposed filter but with more complexity. Having a very sharp transition band, wide stopband, and low insertion loss, their filter performed well, but the suppression level in the stopband region was poor, and the size was relatively large.

In this letter, a microstrip LPF using a T-shaped resonator loaded by open stubs, stepped impedance, and a patch structure is presented to obtain a sharp transition band, wide stopband, low insertion loss, and desirable return loss in the passband.

II. Resonator Design

The design process of the resonator is shown in Fig. 1. Figures 1(a), 1(b), and 1(c) respectively show a T-shaped resonator, a T-shaped resonator loaded by open stubs, and a T-shaped resonator in an asymmetrical form. The parameters related to these structures are a_1=4.23 mm, a_2=0.2 mm, a_3=5.2 mm, a_4=1.8 mm, and a_5=2.1 mm. Their frequency responses are shown in Fig. 1(d). The T-shaped resonator has a high cut-off frequency. The addition of the open stubs results in the increment of capacitance, which moves the cut-off frequency slightly closer to the lower frequency. By connecting

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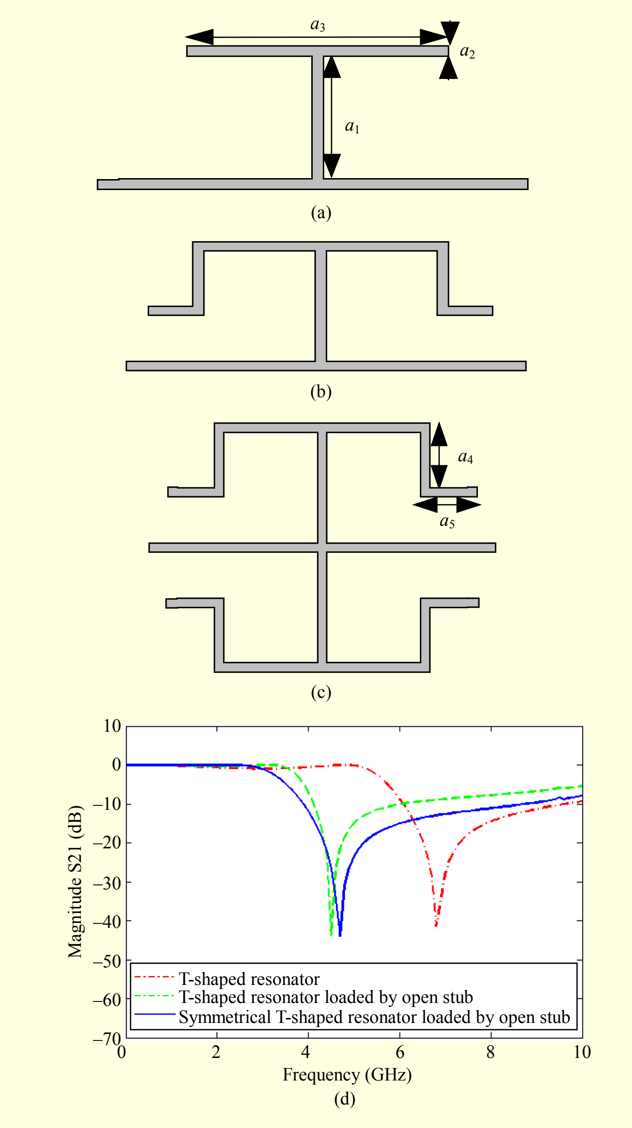

Fig. 1. (a) Layout of T-shaped resonator, (b) layout of T-shape resonator loaded by open stubs, (c) symmetrical T-shaped resonator loaded by open stubs, and (d) frequency responses of (a), (b), and (c).

the resonator in a symmetrical form, we achieve a lower frequency and insertion loss. The T-shaped resonator loaded by the open stubs has a sharper response than the symmetrical T-shaped resonator loaded by the open stubs. However, adding a stepped impedance results in the symmetrical structure achieving the sharper response.

To reach a wide stopband and a better attenuation level in the stopband region, multiple attenuation poles should be added. This is achieved by adding the stepped impedance resonators, as shown in Fig. 2(a). The dimensions of the resonator prototype are b_1=1.52 mm, b_2=0.62 mm, b_3=2.71 mm, and b_4=0.78 mm. As shown in Fig. 2(b), the resonator prototype has a sharp transition band and a relatively wide stopband.

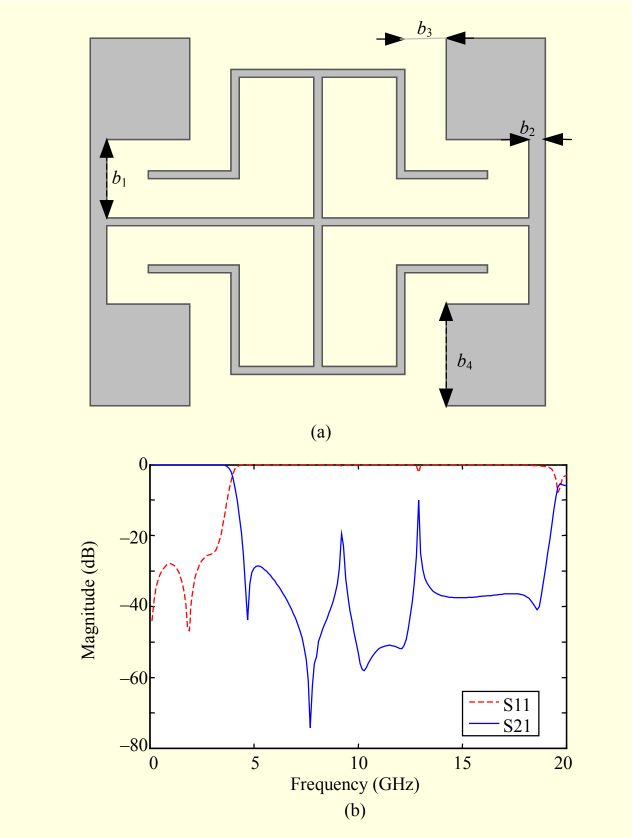

Fig. 2. (a) Layout of resonator prototype and (b) frequency response of resonator prototype.

The high equivalent capacitance and inductance result in a very sharp transition band. For this purpose, the patch structure is added to the resonator prototype, as shown in Fig. 3(a), its parameters being d_1=2.74 mm, d_2=1.4 mm, d_3=0.4 mm, d_4=0.2 mm, d_5=0.63 mm, d_6=0.27 mm, s_1=0.14 mm, s_2=0.52 mm, and s_3=0.1 mm. The proposed resonator has a sharper response than the resonator prototype, as shown in Fig. 3(b).

Assuming that the structure is lossless, its phase velocity can be given by

$$v_p = 1/\sqrt{lc}, \tag{1}$$

where l and c are the equivalent inductance and capacitance, respectively. Also, the dimension of the filter is proportional to the guided wavelength at the cut-off frequency. On the other hand, λ_g is proportional to the phase velocity v_p; therefore, by reducing v_p, we get slow wave propagation. We can overtake low v_p by increasing the equivalent inductance and capacitance in the structure of the resonator. The other parameter relevant to the performance of the proposed resonator is the slow wave factor (SWF). The SWF is given by [10]

$$\mathrm{SWF} = \frac{\lambda_0 \Delta\theta}{360L} + \sqrt{\varepsilon_{\mathrm{eff}}} \tag{2}$$

with

$$\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}(1 + 12\frac{h}{w})^{-0.5}, \quad (3)$$

where L is the physical length of the microstrip line, λ_0 is the guided wavelength, $\Delta\theta$ is the phase difference between the conventional microstrip and the proposed resonator, and ε_{eff} is the effective microstrip permittivity. The variation of the SWF versus frequency is shown in Fig. 3(c). Compared with the conventional microstrip line, the proposed resonator increases the SWF by 497% around 3 GHz.

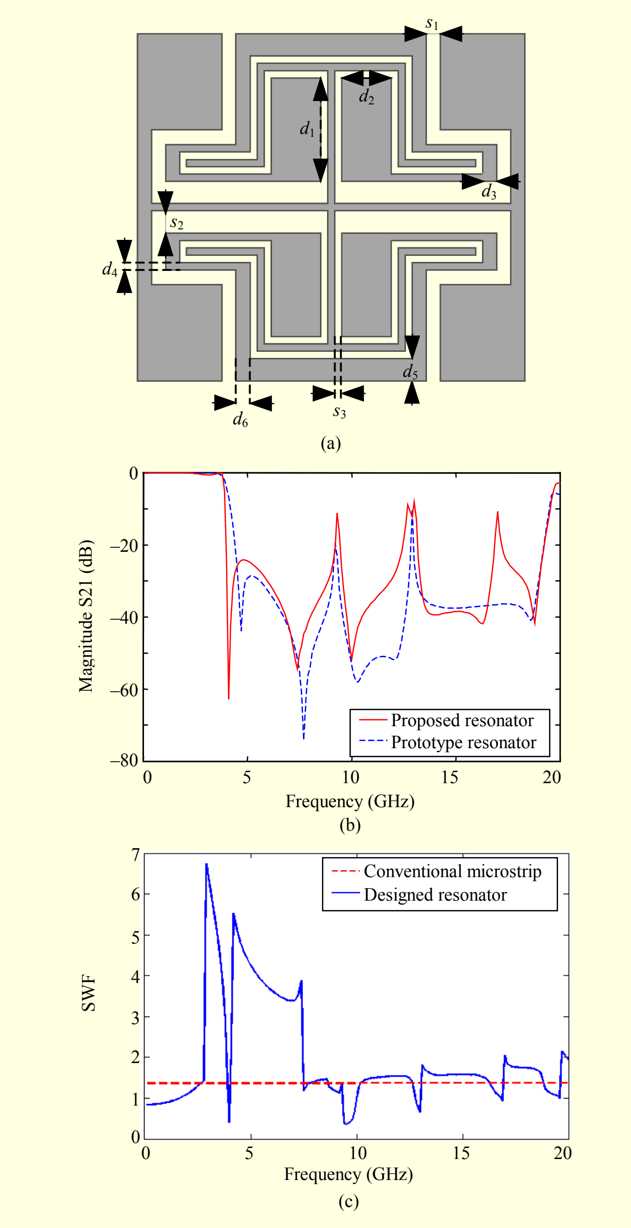

Fig. 3. (a) Layout of proposed resonator, (b) comparison between frequency response of prototype and proposed resonator, and (c) SWFs of proposed resonator and conventional microstrip line.

III. LPF Measured and Simulated Results

An LPF is designed based on the proposed resonator. To achieve a wide stopband with desirable suppression of the harmonics, multiple open stubs are added at the input and output of the proposed resonator. The layout of the designed LPF is shown in Fig. 4(a), and its parameters are L_1=3.05 mm, L_2=2.38 mm, L_3=2.14 mm, L_4=1.93 mm, W_1=0.2 mm, W_2=0.51 mm, L_t=0.4 mm, and W_t=1.56 mm. The microstrip lines at the input and output of the filter with the width W_t are to match the impedance at the input and output ports to 50 Ω. We can control the level of the suppression in the stopband with the variation of the parameters that are related to the open stubs, such as L_1 and L_2. Figure 4(b) shows that by changing L_1 from

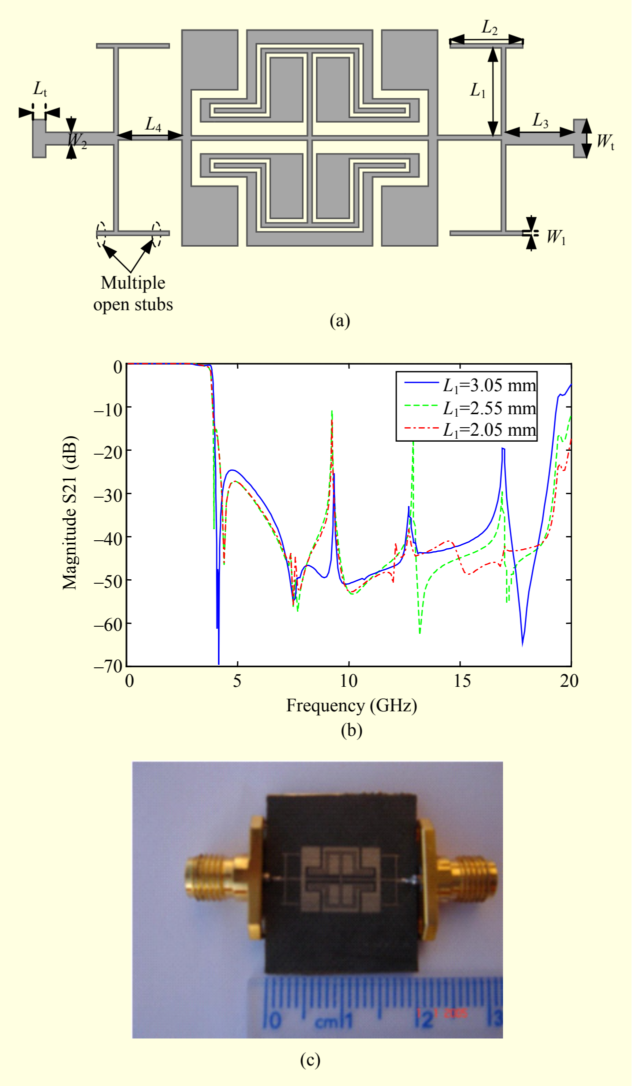

Fig. 4. (a) Proposed LPF, (b) simulation S21 of proposed LPF as function of L_1, and (c) photograph of fabricated LPF.

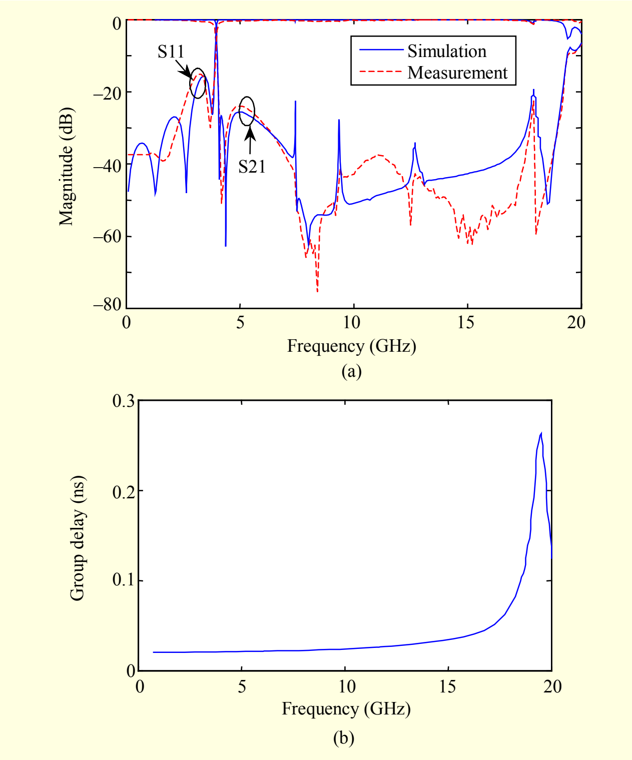

Fig. 5. (a) Simulated and measured responses of filter and (b) group delay of proposed LPF.

3.05 mm to 2.05 mm, the attenuation level in the stopband region is decreased.

Each open stub is equivalent to a shunt capacitor to ground. On the other hand, at the high frequency, the open stubs present a short circuit to the ground and cause the transmission zeros or attenuation poles in the stopband region. Therefore, the addition of open stubs to the proposed resonator causes the attenuation level in the stopband region to be increased.

A photograph of the fabricated LPF is shown in Fig. 4(c). The LPF is fabricated on a substrate with a thickness of 20 mil, relative dielectric constant of 2.2, and loss tangent of 0.0009. The filter is simulated by the method of momentum in ADS software. Agilent network analyzer N5230A is used for the measurement. The simulation and measurement results agree, as shown in Fig. 5(a). The LPF has a cut-off frequency equal to 4 GHz and a wide stopband with a rejection level better than –20 dB from 4.04 GHz up to 19.2 GHz. The passband insertion loss is 0.15 dB, and the return loss is better than –15.2 dB up to 3.72 GHz. The transition band of the filter is 0.04 GHz. The other parameter that illustrates desirable performance of the designed filter is the group delay. As shown in Fig. 5(b), the group delay in the passband region has a maximum variation of 0.27 ns. By including the input and output matching impedance, the size of the proposed LPF is about 19.83 mm × 8.64 mm. The proposed filter in comparison to other filters in [3] to [8] has notable reduction in the transition band and stop bandwidth. Additionally, a wider stopband and sufficient response in the passband region is achieved. Also, in comparison to [9], not only is the transition band improved but the proposed filter has better performances, for example, regarding the stop bandwidth and attenuation level of harmonics in the stopband region.

IV. Conclusion

In this letter, the design of a microstrip lowpass filter with a sharp transition band, wide stopband, and desirable slow wave factor characteristics was presented. This filter was simulated, fabricated, and measured, and the results reflected agreement. The characteristics in the passband and stopband of the proposed filter evidence its applicability in modern communication systems.

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