Compact Microstrip Lowpass Filter with Ultra-Wide Rejection-Band

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***Abstract*—A lowpass filter with wideband stopband is developed using microstrip line and proposed in this paper. It consists of shunt stepped-impedance open-circuited stubs and unit elements. The electrical length of the open-circuited stubs is chosen to be twice the length of the unit elements at a specific frequency. As a result, the filter can exhibit additional transmission zeros inside the rejection band and close to the cut-off frequency. Hence, the filter can provide an equal ripple performance with very high selectivity. The proposed design is verified by EM-simulations and experiment. A good agreement is attained between the calculated, simulated and measured results. The measured filter shows excellent performance with an extended stopband.**

Keywords—Microstrip filter; lowpass filter; stub-line filter, transmission line filter;

I. Introduction

RF/microwave low pass filters (LPFs) are key passive components for wireless communication systems and applications such as suppressing spurious harmonics and blocking unwanted signals. Features that distinguish between LPFs vary from low cost, compact size, low insertion loss and wide stopband. Microstrip low pass filters are one of the most common type of LPFs [1]. This is due to their advantages of low cost, ease of integration with active components and ease of fabrication. Various topologies have been introduced to design microstrip low pass filters addressing the bandwidth, rejection level and the selectivity of such filter [2]-[24]. The first lowpass filter design using microstrip lines is constructed of stepped-impedance lines [1]. The design method of stepped-impedance filter is very simple but the filter has poor transition and the insertion loss attenuation level at the stopband is limited. The attenuation level at the rejection band can be enhanced by replacing the low-impedance line with a λ/4 open-circuited stub [2]. Different techniques and structures have been implemented to improve the stepped-impedance filter performance such as slot-back microstrip line [3], defected ground-plane structures (DGS) slot [4]-[10], stepped-impendence hairpin resonators [11-14], stepped impedance spiral resonator [15] and folded stepped-impedance resonators [16]. Alternatively, microstrip lowpass filters can also be designed using a combination of a transformed radial stub (TRS) and DGSs [17], rat-race directional couplers [18], T-shaped microstrip resonator cells [19], triangular, radial or circular-shaped patch resonators [20]- [21], multimode resonators [22] or a star shaped resonator [23].

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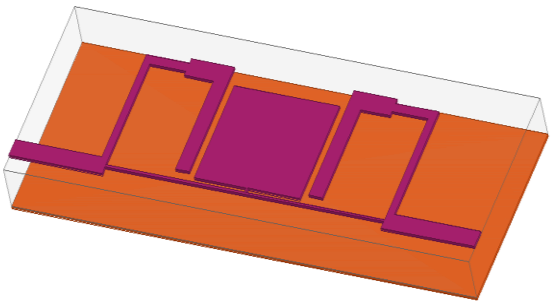

Fig. 1. 3-D illustration of the proposed LPF.

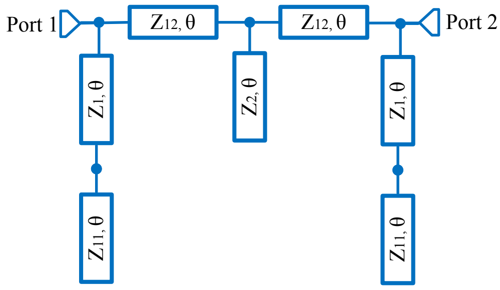

Fig. 2. Equivelant circuit model of proposed LPF.

Quarter-wavelength open-circuited stubs are alternative components to design lowpass microstrip filter which is called stub-line filter [2]. However, stub-line filters always suffer from undesired harmonics and very narrow stopbands. The stopband of the stub-line filter can be widened by introducing a cross-coupling between the filter feed lines [24].

In this paper, a compact microstrip lowpass filter with an extended stopband is proposed. The filter is comprised of shunt stepped-impedance lines and unit elements as shown in Fig. 1. The filter design is based on transmission line filter with open-circuited stubs. In order to extend the stopband and increase the selectivity, the conventional open circuited stubs are replaced with stepped-impedance open-circuited stubs. Hence, the filter can exhibit new transmission zeros at the rejection band which widen the rejection band and enhance the performance. The

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proposed designed is realized using microstrip lines, simulated and measured. The filter design, analysis and measurement results are included.

II. Design and Analysis

A 3-D demonstration of the proposed microstrip layout is depicted in Fig. 1. Fig. 2 illustrates the equivalent transmission line circuit model for the proposed structure. As illustrated in Fig. 2, the filter consists of two symmetric two-section open-circuited stubs and one shunt open-circuited stub separated by two symmetric unit elements. The characteristic impedances of the two-section open-circuited stubs are defined by Z_1 and Z_{11} whereas the characteristic impedance of the shunt open circuited stub is donated by Z_2. Moreover, the characteristic impedance of the unit elements is defined by Z_{12}. The electrical length of each circuit model element is defined by θ.

The filter is designed to exhibit a lowpass performance with a sharp rate of attenuation a cut-off frequency at 2.4 GHz and a very-wide rejection band. The circuit model of the filter is optimized using a computer-aided design (CAD) software to define the desired values of the circuit parameters. The optimized values are found to be as follows: $Z_1 = 101.7\Omega$, $Z_{11} = 47.5\Omega$, $Z_{12} = 159\Omega$ and $Z_2 = 12.1\Omega$. In order to obtain a wide rejection band and a very high selectivity, the filter is built to generate three symmetric attenuation poles within the stopband as displayed in Fig. 3. Therefore, the electrical length (θ) of the circuit parameters is chosen to be a quarter-wavelength ($\pi/2$) at the mid-stopband frequency (f_o) of 8.0 GHz. As a result, the one-section open-circuited stub (Z_2) generates one transmission zero at f_o. Since the total length of each of the two-section open-circuited stub at f_o is about half-wavelength (2θ), both of stepped stubs generate two transmission zeros; f_{z1} and f_{z2}. These two transmission zeros are symmetric to f_o, for instant; $f_o - f_{z1}$=f_{z2} -f_o. Therefore, the filter demonstrates a total of three attenuation poles within the stopband. For $Z_1 = Z_{11}$, the two symmetric transmission zeros (f_{z1} and f_{z2}) occur at $f_o/3$ and $5f_o/3$, respectively. However, the locations of these two transmission zeros and the attenuation level can be controlled by changing the values of $Z_1$and Z_{11}. Fig. 4 shows the filter performance with different values of $Z_1$and Z_{11}. It can be noted that the selectivity of the filter can be enhanced and the stopband can be extended by moving the first transmission zero near the cut-off frequency of the filter. However, there is a trade-off between the selectivity, the bandwidth, and the insertion loss attenuation level at the stopband. For example, when increasing the selectivity, the stopband increases but the attenuation level of the insertion loss decreases.

III. Simulation and Experiment

The filter is developed to exhibit a lowpass performance with a cut-off frequency at 2.4 GHz, a 20-dB return loss with three ripples inside the passband, three attenuation poles inside the rejection band at 3.5, 8.0 and 12.5, and insertion loss attenuation of 30-dB at the stopband. Therefore, the circuit parameters are chosen to be as follows: $Z_1 = 101.7\Omega$, $Z_{11} = 47.5\Omega$, $Z_{12} = 159\Omega$ and $Z_2 = 12.1\Omega$ and $\theta = 90°$ at 8.0 GHz. A RT-

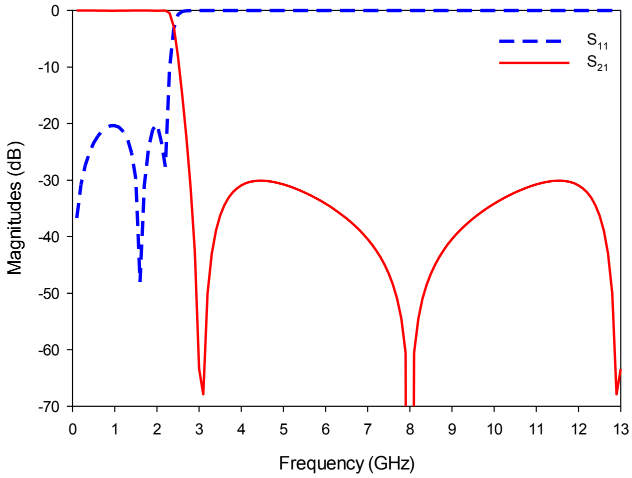

Fig. 3. Calculated performance of the filter with $Z_1 = 101.7\Omega$, $Z_{11} = 47.5\Omega$, $Z_{12} = 159\Omega$, $Z_2 = 12.1\Omega$ and $\theta = 90°$ at a frequency of 8.0 GHz.

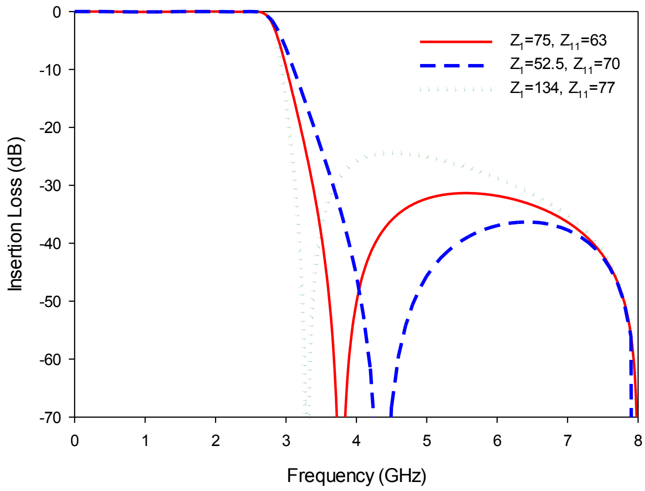

Fig. 4. Calculated result of the filter displayed in Fig.2 with $Z_{12} = 159\Omega$, $Z_2 = 12.1\Omega$, $\theta = 90°$ at a frequency of 8.0 GHz and with vay values of Z_1 and Z_{11}.

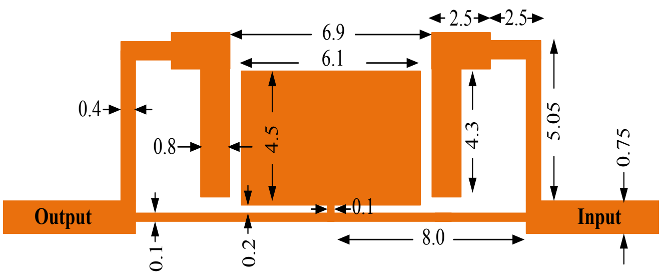

Fig. 5. The schemtics of the proposed LPF (unit:mm).

Duroid/5880 microtrap substrate with a thickness of 0.254 mm and εr = 2.2 is chosen for the filter design. The final microstrip layout with the physical dimensions for the filter is depicted in Fig. 5. The two-section open-circuited stubs are bent to shrink the overall size of the filter. Using a commercially available full-wave EM simulator [25], the microstrip layout is simulated and the result is compared with the theoretical performance as shown in Fig. 6. As can be seen, excellent agreement is found between the simulated and calculated results. Both simulated and calculated results show equal ripple at the passband and the stopband. Using a printed-circuit board technology, the design is successfully fabricated and measured. The fabricated prototype is shown in Fig. 7 which occupies a compact size of about 16.9 mm by 6.0 mm. The measured results are in a good agreement with the simulated results as shown in Fig. 8. The attenuation of the insertion loss is more than 20-dB at the stopband.

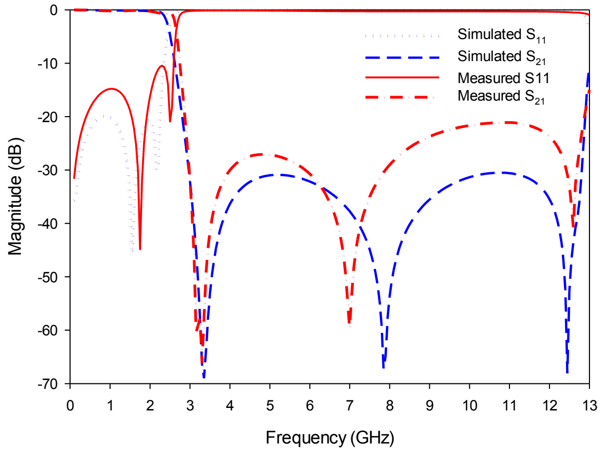

Fig. 6. Comparision between measured and simulated results.

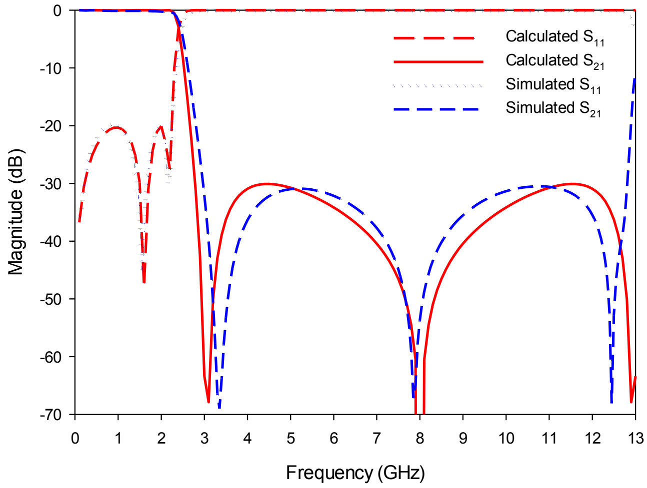

Fig. 7. Calculated and EM-simulated results of the LPF.

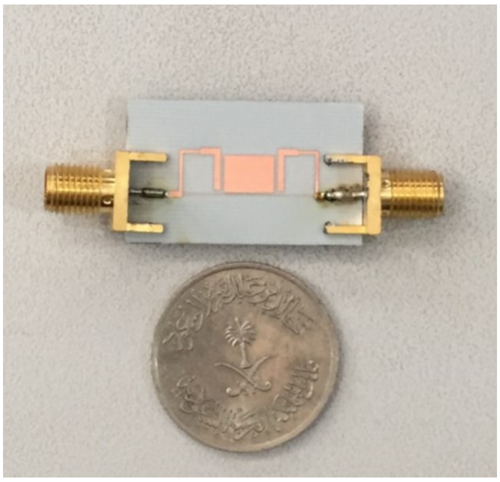

Fig. 8. Photograph of the prototype.

IV. CONCLUSION

In this paper, a lowpass filter with wideband stopband has been developed and presented. It consists of shunt stepped-impedance open-circuited stubs and unit elements. The electrical length of the open-circuited stubs has been chosen to be twice the length of the unit elements at the mid-stopband frequency. As a result, the filter can exhibit additional transmission zeros inside the rejection band and close to the cut-off frequency. Hence, the filter can provide an equal ripple performance with very high selectivity. The proposed design has been verified by EM-simulations and experiment. A good agreement has been attained between the calculated, simulated and measured results. The measured filter has the advantages of high selectivity, low insertion loss at the desired band, good attenuation level at the stopband and compact size.

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