A Compact Tunable Triple Stop-Band Filter Based on Different Defected Microstrip Structures

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Abstract **─** A compact triple stop-band filter based on different defected microstrip structures is proposed, fabricated and measured to filter out the undesired narrowband signal interferences against UWB systems. A meander line slot (MLS), a U-shaped slot (USS) and a spur line (SL) are etched on a 50-Ohm microstrip line to achieve the expected triple stop-band function and to provide a good tunable characteristic by selecting the proper dimensions of the MLS, USS and SL. The equivalent circuit model and its simulations are presented to evaluate the designed triple stop-band filter. Simulated and measured results are given to demonstrate that the proposed triple stop-band filter has controllable center frequencies and compact size.

Index Terms **─** Defected microstrip structure, meander line slot, spur line, triple stop-band filter, U-shaped slot.

I. INTRODUCTION

Recently, high data rate wireless communication systems have achieved much more attention such as ultra-wideband (UWB) system [1-3]. However, there are several narrowband systems overlap with the UWB system and these narrowband systems have been used for a long time, and hence, they may give potential interferences to the UWB system [3]. To give resistant to these interferences, stop-band filters are necessary to suppress these unexpected interference signals. Then, many filters have been reported in recent years. On the other hand, defected ground structure (DGS) has been widely used to design low-pass and stop-band filters [4-9]. However, the DGS may leak electromagnetic wave and might give harmful radiation from the defected ground plane.

To overcome this drawback of the DGSs, defected microstrip structures (DMSs) have been presented and used to develop stop-band and low pass-band filters [9-13]. The DMSs are carried out by cutting various slots in the microstrip line rather than etching slots in the ground planes. These DMSs can effectively reject unwanted electromagnetic waves in special frequencies and directions, which is similar to the DGSs. Moreover, The DMS is easy to integrate with the planar microwave circuits owing to its simpler circuit model and less electromagnetic radiation noise interferences. In addition, the DMS has smaller size because it has higher effective inductance in comparison with the DGSs. A basic DMS has been realized by a T-shaped or L-shaped slot which consists of a horizontal slot and a vertical slot in [10-21]. The horizontal slot and vertical slot can control the equivalent inductance and capacitance of the DMS [10], respectively. Based on the advantages of the DMSs, they have been widely studied and utilized for filter designs and crosstalk reductions. Although many DMS-based filters have been reported, most of them can only provide single or dual filtering bands.

In this paper, a compact triple stop-band filter is proposed, fabricated and measured to suppress the undesired narrowband signal interferences, which is implemented by using different defected microstrip structures (DMSs). The DMSs are etched on a 50-Ohm microstrip line to achieve the expected triple stop-band function and each stop-band can be controlled by the corresponding DMS. The proposed tri-stop-band filter is optimized by using the HFSS, and its equivalent circuit model and electromagnetic simulations are presented to evaluate the designed triple stop-band filter. Also, the proposed filter is fabricated and measured to verify the simulations. Simulated and measured results demonstrate that the proposed triple stop-band filter has controllable

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center frequencies and good stop-band characteristics.

II. TRIPLE STOP-BAND FILTER DESIGN

The configuration of the proposed triple stop-band filter is well designed and described in Fig. 1. The proposed filter consists of a meander line slot (MLS), a U-shaped slot (USS) and a spur line (SL) which are etched on a 50Ω microstrip line. Each DMS cell controls a stop-band, and hence, these three stop bands can be designed independently. The three stop bands are first designed based on the DMS theory presented in [10]. The proposed triple band-stop filter is printed on a Rogers RT/Duroid 5880 substrate with a relative dielectric of 2.2 and a thickness of 0.784mm. The stop-band characteristic of the DMS is controlled by changing the effective capacitance and inductance of the DMS because of the variable electric length, which can be implemented by adjusting the dimensions of the DMSs. In fact, the MLS controls the lower stop-band operating at 3.5GHz, while the USS controls the middle stop-band which operates at 5.8GHz. The upper band operating at 8.5GHz is controlled by the SL and the high-order of DMS-1. Then, the HFSS is used to analyze the effects of the dimensions on the stopband characteristics to get the desired stop bands. The proposed filter is optimized by using the high-frequency structure simulator (HFSS) based on finite element method (FEM) and the optimized parameters are X=32, Y=2.5, x1=7, x2=5, x3=10.5, x4=5.8, s1=0.1, s2=0.1, s3=0.55, s4=0.25, s5=0.6, s6=0.2, h1=0.3, h2=0.4, h3=0.35 (All units: mm).

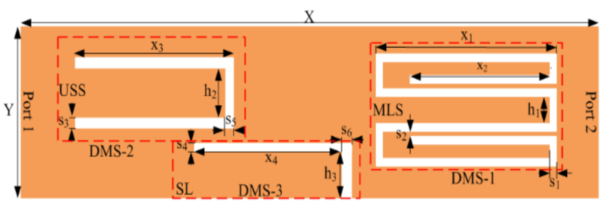

Fig. 1. Geometry of the proposed triple stop-band filter.

III. RESULTS AND DISCUSSIONS

To study the performance of the proposed triple stop-band filter, parameters x1, x3, and x4 are selected in this section to analyze their effects. Herein, to well understand the effects of the key parameters, only one parameter is investigated by using the HFSS with different values while all the other parameters are fixed as the optimized values. The effects of S11 and S21 are shown in Figs. 2, 3 and 4, respectively, where the S11 is to analyze the impedance characteristics and the S21 is to depict the transmission characteristics.

With an increment of x1, the center frequency of the lower stop-band operating at 3.5GHz moves to the low frequency, which is shown in Fig. 2. In this case, the increased length of x1 increases the value of the equivalent inductance of DMS-1 and, hence, the center resonance frequency of lower stop-band changes. Additionally, the upper stop-band is affected since it is controlled by both the high-order resonance of the DMS-1 and the resonance of DMS-3. As x3 increases from 9.4mm to 9.9mm, the center frequency of the middle stop-band shifts toward low frequency and the simulation results are given in Fig. 3. This means that the prolonged length of x3 increases the equivalent inductance of the DMS-2. In this case, the lower and upper stop-bands keep constant. Since the upper stop-band is generated by the high-order mode of the DMS-1 and the DMS-3, the bandwidth and the center frequency of the upper stop-band can be controlled by the dimensions of both DMS-1 and DMS-3. The effects of the x4 on the S11 and S21 are given in Fig. 4. It can be seen that the bandwidth of upper stop-band has obvious effects and x4 also affects the lower resonance because of the coupling between the SL and the USS.

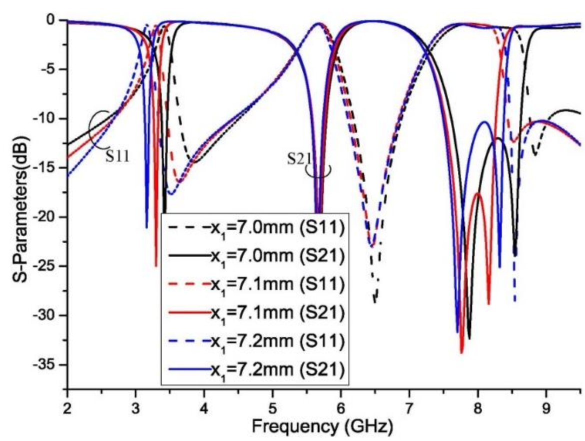

Fig. 2. Effects of x1 on the S11 and S21.

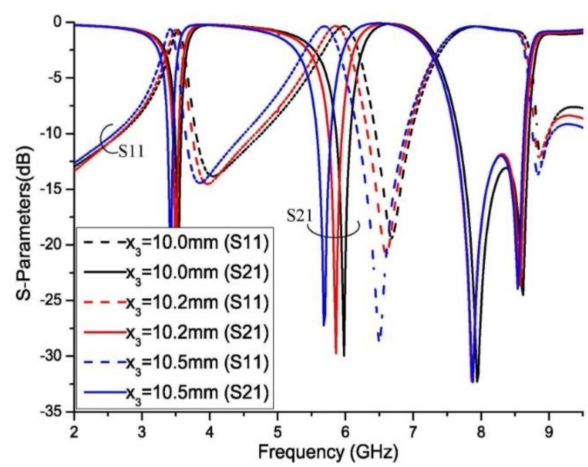

Fig. 3. Effects of x3 on the S11 and S21.

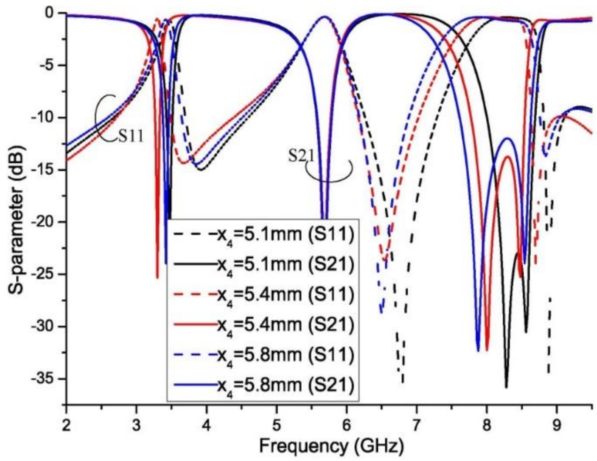

Fig. 4. Effects of x4 on the S11 and S21.

In order to analyze the proposed triple stop-band filter, its equivalent circuit model is extracted and presented to confirm the effectiveness of the simulation, which is obtained based on the Butterworth low-pass filter theory. Based on the defected grounded structure circuit analysis theory, the DMS cell can be analyzed herein. The basis circuit model of the DMS is given in Fig. 5 in comparison with the Butterworth low-pass filter model.

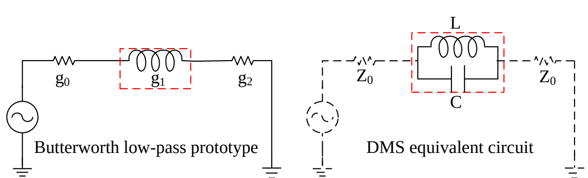

Fig. 5. Equivalent circuit models.

From the previous studies, we know that the impedance of the 1st Butterworth low-pass filter can be modeled as:

$$X_L = \omega' Z_0 g_1, \tag{1}$$

where ω is the normalized angular frequency that the filter operates, g_1 represents the normalized 1st Butterworth low-pass parameter, Z_0 denotes the characteristic impedance which is always equal to 50-Ohm in the engineering design. Then, the resonance of a basis DMS cell can operate at:

$$X_{LC} = [\omega_0 C(\frac{\omega_0}{\omega}) + \frac{\omega}{\omega_0}]^{-1}, \tag{2}$$

where ω_0 is the desired resonance frequency given by the modeled parallel inductance and capacitance. In order to simplify the analysis of the proposed triple band-stop band filter, the mentioned Equations (1) and (2) are equal when $\omega = \omega_c$, where ω_c denotes the cut-off frequency of the parallel LC resonator illustrated in the Fig. 5. Thus, we can get:

$$X_{LC} /_{\omega=\omega_C} = X_L /_{\omega'=1}. \tag{3}$$

According to the Equations (1)-(3), the capacitance and inductance can be obtained by using the following equation:

$$C = (\frac{\omega_C}{Z_0 g_1})\frac{1}{\omega_0^2 - \omega_C^2}, \tag{4}$$

$$L = \frac{1}{4\pi^2 f_0^2 C}. \tag{5}$$

By using the formulas (1)-(5) presented above, the capacitance and inductance of single DMS based stop-band filter parameters can be obtained.

Then, the all the DMS cells have been analyzed to get an integration analysis of the proposed triple band-stop filter. Here, the couplings between the DMS cells have been included in the circuit of the proposed filter to get the effects of the different DMS cells. According to the equivalent circuit model and the analysis of the basic DMS cell in [9-10], the equivalent circuit model of the proposed triple stop-band filter is extracted and is given in Fig. 6. The circuit parameters are obtained by using the formulas given above and the circuit parameters are optimized by using the Advanced Design System (ADS) produced by the Keysight. The parameters are L1=0.344nH, L2=0.316nH, L3=0.306nH, L4=0.372nH, C1=6.291pF, C2=1.098pF, C3=2.567pF, C4=1.098pF, Ls1=-0.4776nH, Ls2=-0.65nH, Ls3=0.6021nH, Ls4=-0.6264nH, Cp1=-0.2596pF, Cp2=0.01532pF.

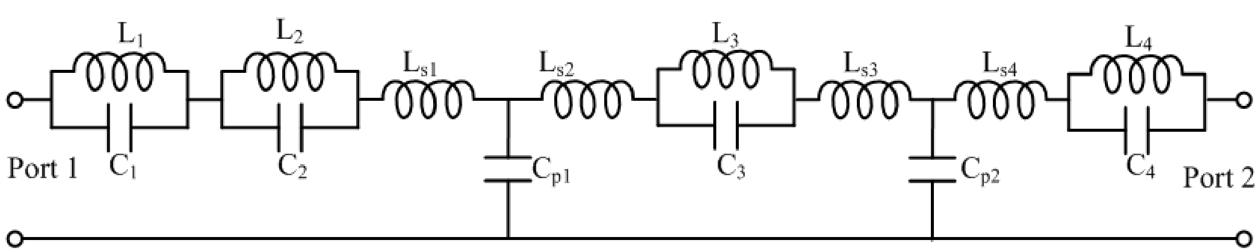

Fig. 6. Equivalent circuit of the proposed tri-stop-band filter.

To verify the performance of the proposed triple stop-band filter, the optimized filter is fabricated and its performance is measured by using Agilent N5224A vector network analyzer. It can be seen from Fig. 7 that the measurement approaches well to both the circuit and HFSS simulations. The proposed filter has good frequency selectivity. These transmission zeros are obtained by the coupling of the DMSs and are tunable by adjusting the coupling strength which is implemented by changing the distances between the DMSs. It is worth noting that there are some differences between the measured and simulated results, which may be caused by fabrication tolerances and inaccuracies introduced by manual welding. The measured bandwidths of the designed triple stop-band are 3%, 3.5% and 12.3%, respectively, while the insertion losses at the center frequency are -0.54dB, -0.32dB and -0.43dB, respectively. The triple stop-band filter has a small size of 32mm×2.5mm. Compared with the previously proposed filters [15,20], the proposed triple stop-band filter has a size reduction of 55% and 92%, respectively.

Furthermore, it has a size reduction of 60% in comparison with the DMS filter in [14]. Additively, the proposed filter is flexible in design because of its independently controllable center frequencies and tunable bandwidth, and it has simple structure and compact size, which render it suitable for integrating into a UWB system to mitigate the unexpected interferences.

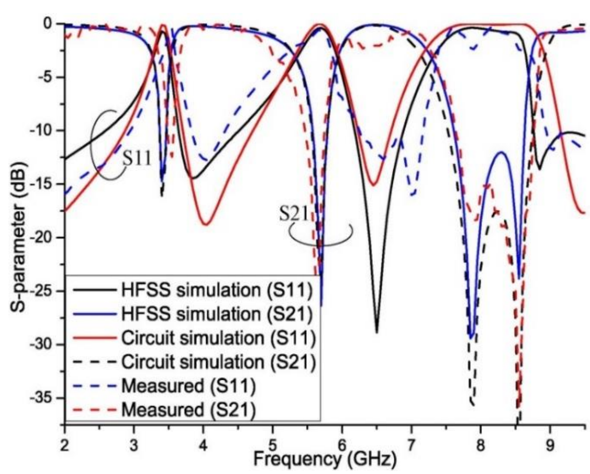

Fig. 7. Comparisons of S11 and S21 of the proposed triple stop-band filter.

IV. CONCLUSION

A compact triple stop-band filter by using DMSs has been proposed and its performance has been investigated by HFSS, circuit simulations and measurement. The proposed tri-stop-band filter with simple and compact structure highly reduced the size in comparison with the previously deigned filters. Additionally, the proposed tri-stop-band filter is easy to design, and its center frequencies and bandwidth of the stop-band can be controlled individually, which gives a high flexibility and wide application. The equivalent circuit and HFSS simulations are presented to evaluate the designed triple stop-band filter. The filter has been fabricated and measured, and the experiment result agrees well with the circuit and HFSS simulations.

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