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Tunable Microstrip Low Pass Filter with Modified Open Circuited Stubs

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Abstract

This paper presents a new design approach to achieve tunable microstrip low pass filters with compact size and good electrical performances. The proposed filter consists of a fork-shaped resonator coupled directly to two transmission lines. First, the low pass filter was designed to have a Chebyshev response with slightly wider bandwidth and high rejection. The second step of our design approach was to replace the transmission line in the middle of the circuit by a fork-shaped resonator. In order to control the tunability of the low pass filter, three identical capacitors was integrated in the extremities of the open circuited stubs. The simulation results obtained with schematic environment of (Advanced Design System) ADS solver show that it is possible to obtain a tunable low pass filter with low loss, high rejection, and wide stop band.

Keywords

Fork-Shaped Resonators, Low-Pass Filter, Microstrip, Open Circuited Stubs, Tunable Capacitors

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1. Introduction

Filters are electronic circuits characterized by a transfer function and used to control the frequency response of a microwave system. They provide a transmission at frequencies within the passband of the filter and reject the unwanted signal in the stopband [1]. Filters achieved using microstrip technology are widely used in many telecommunication systems such as (Radio, TV, Mobile phone, Satellite communication systems, Radars). In fact, they are very compact compared with other filters such as waveguided filters.

The drastic constraints imposed on the electrical performances and the fabrication cost of the modern communication systems; require the design of new RF filters with good electrical performances and compact size. In this context, it is primordial to search new techniques able to provide small filters with good frequency response. It is possible to qualify the tunable filters as one of the most promising alternative used to achieve RF filters. In fact, many research have been proposed in literature to design tunable microstrip filters such using, varactor-loaded open ring resonator [2], square loop resonator and varactor diodes [3], stub-loaded open loop resonator [4], patch reference elements and a varactor diode [5], three different open-stubs loaded in a SIR [6], open-circuited stub-loaded resonators with varactors and PIN diode [7].

This paper proposes a new method to reduce the size of a low-pass filter by using tunable capacitors connected to a new structure of microstrip low-pass filter with open circuited stubs. Our design approach begins with the design of a conventional low pass filter based on open circuit stubs. The classical design method is introduced. Once the circuit is designed, the stub in the middle of the circuit was replaced by a fork-shaped transmission line. This technique is used to give the designer more freedom to control the frequency response of the filter. The last phase of our design approach consists of integrating variable capacitors at the extremities

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of the filter. The simulation results obtained with ADS solver show good electrical performances in terms of insertion loss, rejection, and stop band. Finally, this method has shown that it is possible to reduce the size of the circuit by setting the cutoff frequencies at low frequencies while improving the response of the filter.

2. The Design of Low Pass Filter with Open Circuited Stubs

The first part of this paper presents the basic concepts necessary to design RF filters based on microstrip lines structures. In fact, the classical approach to design a filter begins by the choice of the response type including passband ripple and the number of reactive elements [8, 9].

In this section, the three-order filter has a Chebyshev response with a 0.1 dB ripple and a cut off frequency f_c of 1 GHz. Z_0 is the source impedance, which is usually 50 ohms. The element values g_k for the low-pass filter prototype can be given by the table 1.

Table 1. Element Values for Chebyshev Low pass Prototype Filter.

For passband ripple L_{Ar}=0.1 dB (g_0=1.0, Ω_c=1)					
n	g_1	g_2	g_3	g_4	g_5
1	0.3052	1.0			
2	0.8431	0.6220	1.3554		
3	1.0316	1.1474	1.0316	1.0	
4	1.1088	1.3062	1.7704	0.8181	1.3554

Where g_i denote the inductive and the capacitive elements of the low pass filter prototype.

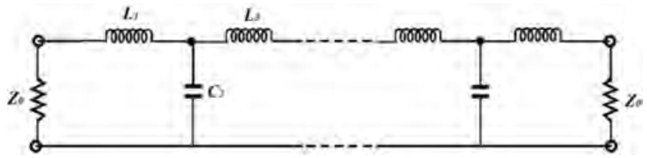


Figure 1. Low pass prototype filter.

As can be seen, figure 1 presents the low pass prototype filter. The L-C elements values can be calculated by the following equations:

$$L_i = \frac{1}{2\pi f_c} Z_0 g_{L_i} \tag{1}$$

$$C_i = \frac{1}{2\pi f_c}\frac{1}{Z_0} g_{C_i} \tag{2}$$

After this first step, it is necessary to find an appropriate microstrip realization in order to achieve the low pass filter. In fact, many conventional structures can be chosen to realize this circuit. In this paper, we opt for the LPF with open circuited stubs.

The general structure of a low pass filter with open circuited stubs is presented in the figure 2. It can be clearly seen that the structure of this kind of circuit is a cascade of low and high impedance. It should be noticed that this structure was chosen because it is a simple and easy circuit that can be realized with the microstrip technology [10].

Figure 2. The conventional structure of the Low pass filter with open circuited stubs.

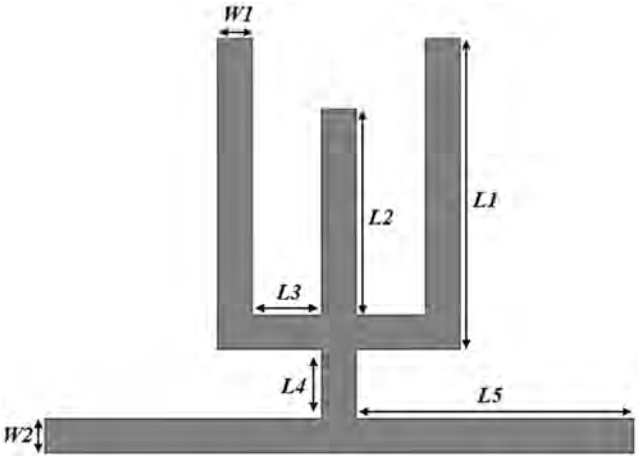
The physical length of the low and high impedance elements are obtained using the following relations:

$$l_L = \frac{\lambda_{gL}}{2\pi}\sin^{-1}\left(\frac{\omega_c L}{Z_{0L}}\right) \tag{3}$$

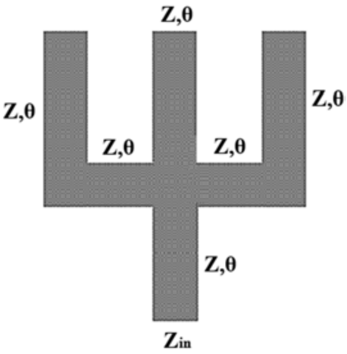
$$l_C = \frac{\lambda_{gC}}{2\pi}\tan^{-1}\left(\omega_c c Z_{0C}\right) \tag{4}$$

Where Z_{0C} and Z_{0L} are respectively the characteristic impedances of the low and high impedance lines. λ_{gc} and λ_{gL} denote the guided-wavelengths.

In this work, our design approach aims to replace the transmission line section in the middle of the filter by a fork-shaped transmission line. The main interest of this technique is to give the designer more freedom to change the geometrical parameters in order to reduce the cut-off frequency and the pass band or to improve the rejection and the stop band. The figure 3 presents the structure of this fork-shaped transmission line and the layout of the proposed low pass filter with open circuited stubs.



(a)



(b)

Figure 3. (a) The layout of the low pass filter with open circuited stubs (b) The structure of the proposed fork-shaped transmission line.

In order to analyze our new design approach, it is indispensable to calculate the characteristic impedance of the proposed transmission line. In fact, we suppose that each section of this transmission line has an impedance characteristic Z_0 and an electrical wavelength θ. This supposition is used to simplify the calculation of the input impedance.

The input impedance Z_{in} of the fork-shaped can be given by the equation (5):

$$Z_{in} = j\frac{Z}{4}\left[\frac{3\tan^2\theta - 1}{\tan\theta}\right] \quad (5)$$

Therefore, the electrical length and the characteristic impedance of each section in the fork-shaped transmission line can be obtained by comparison to the characteristic parameters of the conventional structure introduced in the first part of this section.

If we consider the proposed fork-shaped transmission line as a resonator, we can say that the resonance occurs when $Z_{in}=\infty$. Based on the equation (5), the resonance condition can be obtained by the following equation:

$$\tan\theta = 0 \quad (6)$$

Thus, we can conclude that the length of the each part in the fork-shaped resonator is the critical parameter which can affect the frequency response of the proposed low pass filter.

The low pass filter was designed using the FR4 substrate characterized by a thickness of 1.6 mm, a relative electric constant of 4.4, a loss tangent of 0.025 and a conductor thickness of 35 um. The proposed filter is very compact with an overall size equal to (17 mm × 12 mm). Table 2 gives the dimensions of each part of the low pass filter.

Table 2. The dimensions of the low pass filter with open circuited stubs in (mm).

L1	L2	L3	L4	L5	W1	W2
9	6	2	2	8	1	1

The figure 4 gives the simulation results of the proposed low pass filter with open circuited stubs. We can clearly observe that the filter presents remarkable frequency response. The filter is designed for a cutoff frequency of 2.1 GHz with low insertion loss and high return loss better than 30 dB. The circuit presents also a wide stop band up to 4 GHz with an attenuation better than 20 dB. In addition, the high rejection of proposed low pass filter can be attributed to the presence of an attenuation pole near the pass band located at 3.5 GHz with an attenuation of 39 dB.

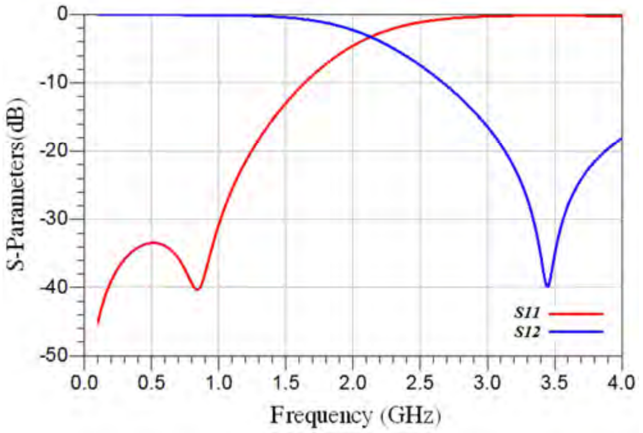


Figure 4. The simulation results of the proposed low pass filter with fork-shaped transmission lines.

3. The Tunable Low-Pass Filter with Open Circuited Stubs

In this section, we are interested by the design of a tunable low-pass filter. For that, three tunable capacitors were directly connected to the open stubs of the proposed filter. It should be noticed that to conserve the symmetry of the proposed structure, the three tunable capacitors would have the same value. Besides, these three tunable capacitors are very useful to control easily the frequency response of the low pass filter. The structure of the proposed low pass filter with tunable capacitors is presented in the figure 5.

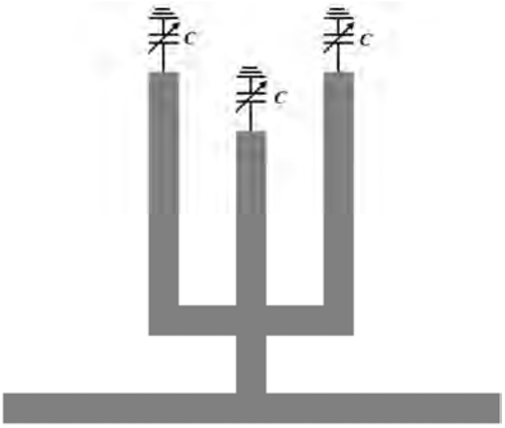


Figure 5. The layout of the tunable low-pass filter with open circuited stubs.

The figure 6 presents the layout of the proposed low pass filter in the schematic environment of ADS solver. As can be seen, three identical tunable capacitors were directly connected to the circuit. The main purpose of these simulations carried out with this simulator is to analyze and to study the behavior of our circuit under different values of the tunable capacitors connected to the open stubs of the low pass filter.

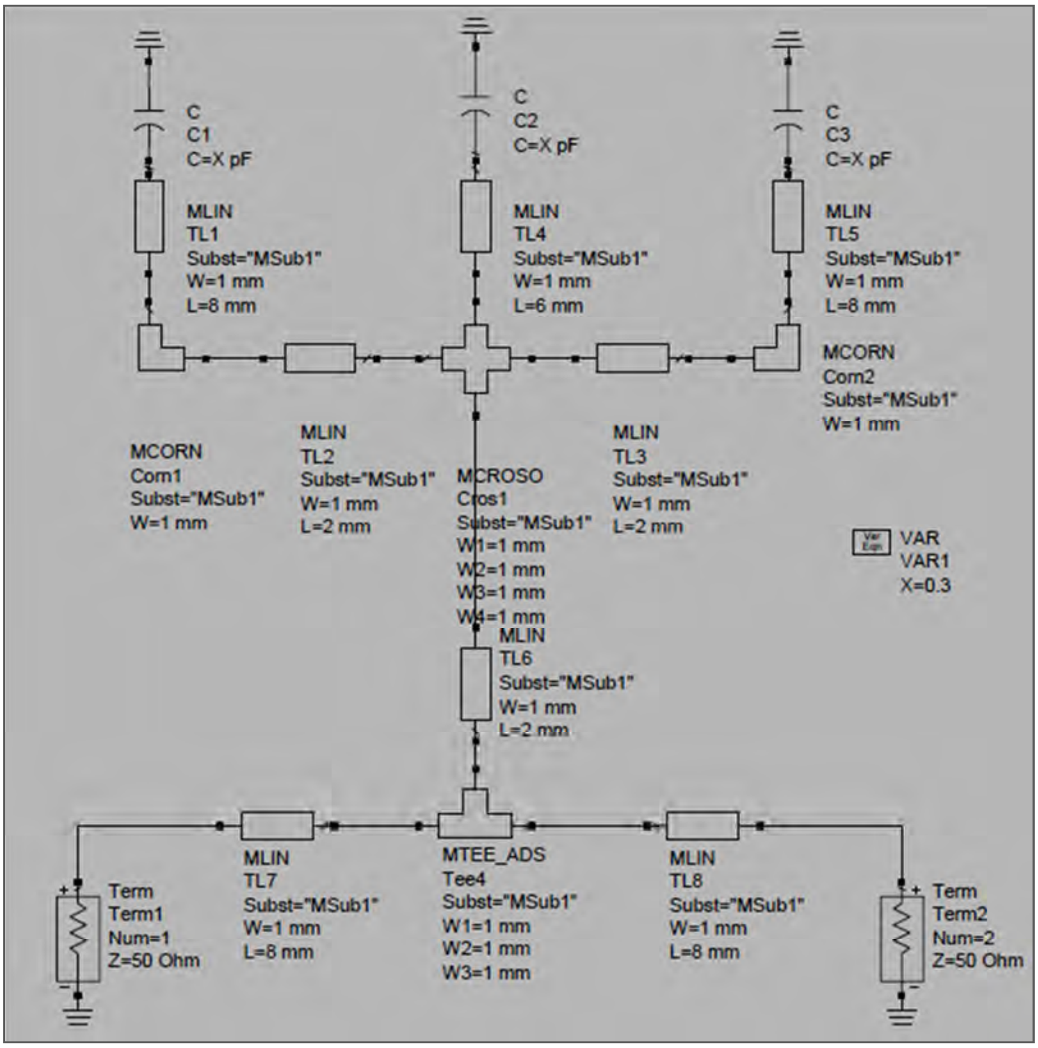
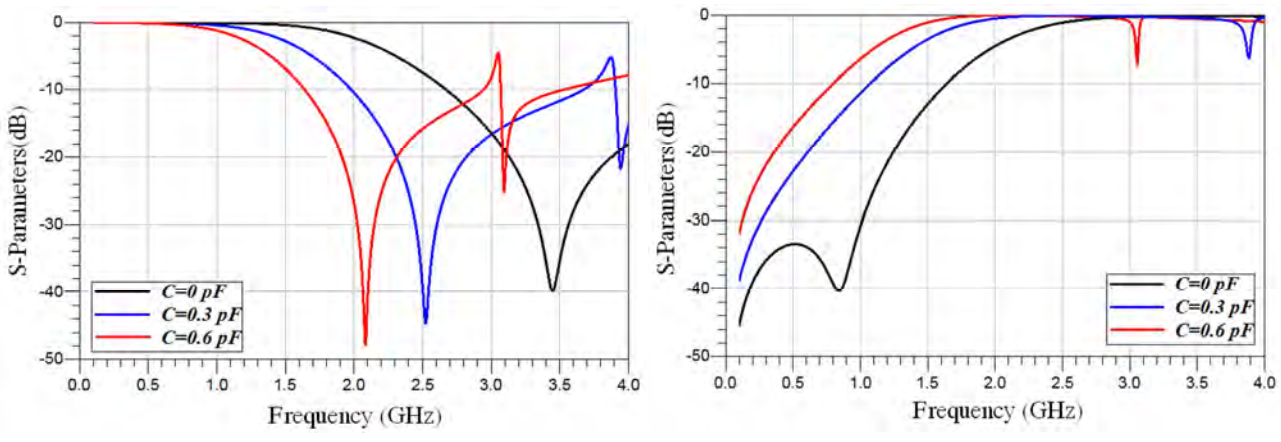


Figure 6. The tunable low pass filter implemented in the schematic environment of ADS solver.



(a) (b)

Figure 7. The simulation results of the tunable low pass filter with open circuited stubs. (a) S_{11} (b) S_{12}.

The figure 7 gives the simulation results of the proposed tunable band-pass filter under different values of the capacitors. In fact, two capacitors of 0.3 pF and 0.6 pF were used and the results were obtained with ADS solver. As can be seen, increasing the value of the capacitors puts the cutoff frequency at low frequencies and decrease the width of the pass band. The cutoff frequency goes from 1.52 GHz for C=0.3 pF to 1.235 GHz for C=0.6 pF. Besides, it can be seen that the added capacitors puts the attenuation poles at low frequencies. However, increasing the value of the capacitors decreases the stop band of proposed filter.

4. Conclusion

In this paper, a tunable microstrip low pass filter with small size and good electrical performances was designed and simulated using ADS solver. The proposed filter consists of a fork-shaped resonators and two transmission line with low impedance characteristic. The filter exhibits very low insertion loss in the pass band and high rejection due to the presence of an attenuation pole near the pass band. Besides, three tunable capacitors were added to the open stubs of the filter in order to control easily its frequency response. It can be concluded from the results obtained in this article that it is possible to design low pass filter with compact size and good frequency response based on modified classical topologies and tunable capacitors. Furthermore, to reduce its cost, this filter was designed on a 1.6 mm FR4 substrate using an effective dielectric constant of 4.4.

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