Research on Dual Bandpass of Wide Stopband Filter with Tunable Center Frequency

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Abstract— A dual passband of wide stopband varactor tuned filter using stepped impedance resonators (SIRs) is proposed in this paper. A varactor is loaded on the middle of the E-shaped resonators, through changing the value of the bias voltage across the varactor, the center frequency of the second passband can be tuned from 1.56 GHz to 2.25 GHz, however, the center frequency of the first passband is fixed and maintained at 1.02 GHz. In fact, it is fixed during the whole process. The relative bandwidth of the first passband is 14.7%, the return loss of is 19 dB and the insertion loss is 0.2 dB. The second passband can tuning from 1.56 GHz to 2.25 GHz with the tuning range of 36.2%. The relative bandwidth almost keep unchanged. The return loss change from 16 dB to 30 dB and the insertion loss change from 0.2 dB to 0.8 dB. This filter proposed in this paper has a great characteristic of harmonic suppression, −20 dB up to 3.5 GHz. There are two advantages of the optimization process. The first is that a filter network is added in the input and output coupling line to depress stopband. The second is that spurlines are added at the input and output coupling line which can add zero between the two passbands, which improved the performance for filter. It is good to improve the selectivity of the filter. The filter proposed in this paper can achieve a compact size, lower insertion loss and wider rang harmonic suppression. Simulations show that the filter proposed is valid and has a good performance.

1. INTRODUCTION

Microwave filter as a basic part of all communication systems, its performance is directly related to the communication quality of the whole system, therefore, the filter is an integral part of communication systems which has attracted a lot of research. At the same time, there is ever increasing shortage of spectrum resources as technology become more robust. The distribution of electromagnetic field and wave in the air is becoming more and more complex, tunable filter technology emerge as the times' require, obtains the wide spread research and application microstrip filter has the advantages of miniaturization, so the tunable filter that based on the microstrip has become an interesting area of study. There is neither need to redesign the structure of the system nor reprocessing circuit board, w we need to do is transfer switch and electrically tunable filter can realize the new assume and function.

There are mainly four types of tuning methods [1]: mechanical tuning method ferrite tuning method RFMEMS tuning method and varactor diode tuning method. Mechanical tuning method has the advantage of low price and is easy to make. But its volume is too large and its tuning speed is too low and therefore it can't meet the requirements any more [2]. Ferrite circuit has a large volume too, we need to adjustable magnetic field to control it. The use of the condition is too harsh, we abandon it [3]. The RFMEMS tuning method has a very small loss and can withstand high power, however, its switching speed is slow, adjustable rate is small (relatively high tuning voltage is needed, usually tens of volts or even hundreds of volts), it is difficult to integrate it with other circuits. It requires very strict encapsulation, and this package is very expensive. Therefore, its application is limited. Varactor diode tuning method has a high tuning speed and the design cost is low, besides, it is has the advantage of planar integrated ability. That's the reason it has gained wide spread application. We conclude that it offer the best solution to solve the tuning problem.

Stopband depress of tunable filter has been a problem for a long time. The new filter network combine with traditional methods of widening the stopband can be a very effective way to solve this problem [4]. In this paper, a new filter network is added in the input and output coupling line to depress stopband. Adding spurline is a traditional method to widening the stopband [5]. In order to improve the performance of the tunable filter further, spurline of carefully designed is added in the input and output coupling lines. Bending couple line can increase the coupling degree, to some extent, reduce insertion loss of passbands, which is another way to improve the performance of the filter.

2. THEORY AND EQUATION

2.1. Basic Structure of Stepped Impedance Resonaator

There are three types of stepped impedance resonators (SIRs), which are $\lambda/4$ SIR $\lambda/2$ SIR and λ SIR. This paper adopt $\lambda/2$ SIR, by changing the impedance ratio and the electrical length of the two impedance line, we can control its resonant frequency [6]. The basic structure is shown in Fig. 1. It is composed by two different transmission lines with the characteristic impedance of K and Z_2, the corresponding electrical length is θ_1 and θ_2 respectively [7]. The Input admittance of Y_{in} is shown in Fig. 1.

$$Y_{in} = \frac{jY_2 2(K\tan\theta_1 + \tan\theta_2)(K - \tan\theta_1 \cdot \tan\theta_2)}{K(1-\tan^2\theta_1)(1-\tan^2\theta_2) - 2(1+K^2)\cdot\tan\theta_1\cdot\tan\theta_2} \tag{1}$$

K is the impedance ratio, we define $K = Z_1/Z_2$ [8]. We take $\theta_1 = \theta_2 = \theta$ for convenient [5], then (1) is simplified as (2)

$$Y_{in} = jY_2 \frac{2(1+K)(K-\tan^2\theta)\tan\theta}{K - 2(1+K+K^2)\tan\theta} \tag{2}$$

Because the resonance condition is Y_{in}, so we put $Y_{in} = 0$, we can derive (3)

$$K = \tan\theta_1 \cdot \tan\theta_2 \tag{3}$$

We put $\theta_T = 2\theta_1 + \theta_2$ into (3), we can derive that

$$\begin{cases} \tan\frac{\theta_T}{2} = \frac{1}{1-K}\left(\frac{K}{\tan\theta_1} + \tan\theta_1\right) & K \neq 1 \\ \theta_T = \pi = 180^\circ & K = 1 \end{cases} \tag{4}$$

We can derive that the resonance depends on electric length of θ and impedance ratio K.

2.2. Design Principle

The filter proposed in this paper is composed of a $\lambda/2$ SIR, an E-shaped resonator and a varactor [9]. The varactor series with E-shaped resonator and load on the center of the $\lambda/2$ SIR. The basic structure is shown as Fig. 2.

The center frequency of the second passband is controlled by the resonant frequency of even model. The resonant frequency of even model is decided to Z_{inc}. Z_{inc} is mainly affected by the varactor, so we can change the center frequency of the second passband by changing the voltage of the varactor. At the same time, the resonant frequency of odd model is not affected.

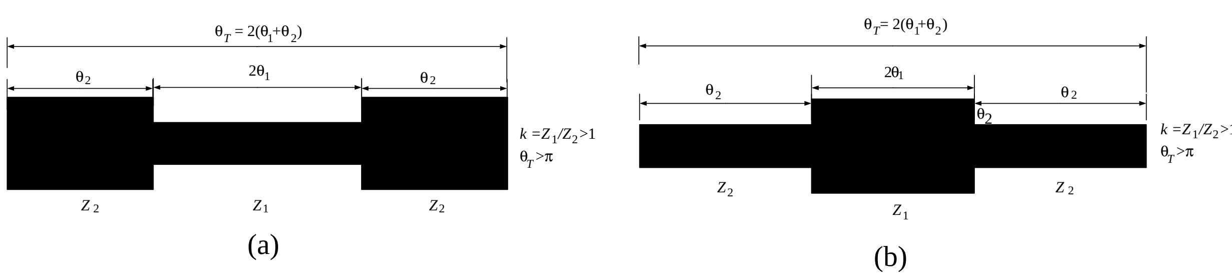

Figure 1: (a) The first form of $\lambda/2$ SIR. (b) The second form of $\lambda/2$ SIR.

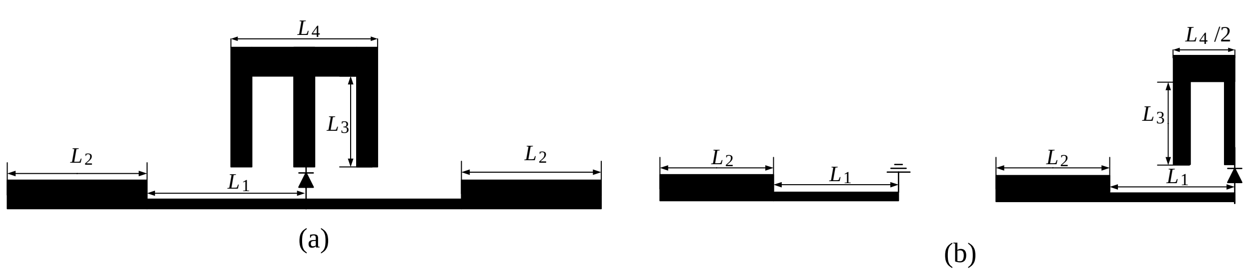

Figure 2: (a) The equivalent model of resonator. (b) The odd model. (c) The even model.

2.3. Structure of Spurline

Spurline is a coplanar microstrip defected structure that is set in the traditional microstrip. It has the advantages of simple compact, easy integration, convenient to use. Spurline as a kind of microstrip defected structure, it have influence to current distribution of filter, thus changing the characteristics of filter [10]. In addition, the spurline has excellent band gap characteristics. It can be used to structure band stop filter, have a good effect on harmonic suppression. The gap of spurline is equivalent to the resonator capacitance, the slot itself can be considered as the resonance inductance [6], the whole circuit is equivalent to a parallel resonant circuit, the resonant frequency is determined by the (6).

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{5}$$

The traditional structure of spurline is shown as in Fig. 3. There are three parameters determine the structure: length a, width s, height b [11]. Typically, capacitance effect is relate to the width, and inductance effect is relate to the length. Therefore, the effective dielectric constant of dielectric substrate have change with the size of spurline [12].

The equivalent circuit structure of the traditional single spurline is shown in Fig. 4. The resonant circuit is represented by LC, the effect of radiation and transmission loss is represented by a resistor R.

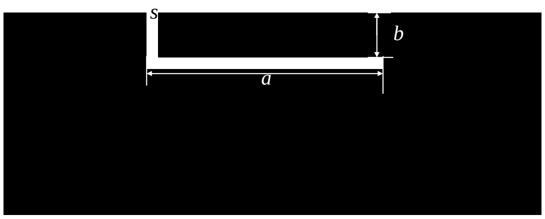

Figure 3: Conventional spurline structure.

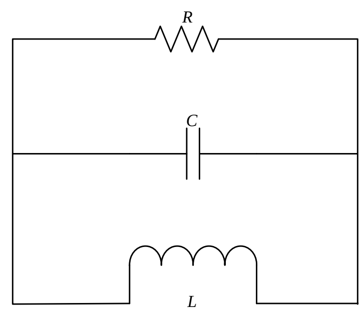

Figure 4: The equivalent circuit of single spurline.

3. SIMULATION AND RESULTS

This section we will describe the design and performance of the tunable dual passband of wide stopband filter. The proposed filter were based on a common substrate with a thickness of 20 mil and relative dielectric constant is 3.48. The type of substrate is ROGERS4350B. This is a very common substrate and easy to buy. A new asymmetric filter network is added between the input and output coupling line. As shown in Fig. 5, which is composed of four sections of curved open stub. The length L_a and L_b determine the filter network stopband characteristics; there exist additional capacitance and cross coupling between L_a and L_b and the input-output impedance line. The multipath effect of cross coupling can further expand the scope of the stop band, reduce quality factor of the passband and make the filter easier to be implemented in Engineering.

As is shown in Fig. 6, parallel coupled lines with value of $50\,\Omega$ is used to feed, the structure is insensitive to the external electromagnetic environment. Spurlines is added at the input and output coupling line, it can add zero point in the two pass band, which play a good harmonic suppression function.

By changing the size of the spurline, we chose the best one, so that the performance of selection of the filter is improved. Feed coupled line is extended and bended, which can increases the coupling degree, to some extent, it reduces the insertion loss. At the center of the E-shaped resonator a varactor is loaded. The varactor involved in this proposed filter is SMV1247 with the tunable capacitance from 0.64 pF to 8.86 pF and the tunable bias voltage range from 0 to 8 V. The filter is symmetric, with the odd ode and even mode, which are independent with each other.

After analysis and simulation the filter using HFSS and ADS, the design parameters are shown as following: $L_1 = 40$ mm, $L_2 = 15.3$ mm, $L_3 = 15.5$ mm, $L_4 = 11$ mm, $L_5 = 10.4$ mm, $W_1 = 1.14$ mm, $W_2 = 2$ mm, $W_3 = 0.9$ mm, $W_4 = 5$ mm. $L_a = 11.14$ mm, $L_b = 14.14$ mm, $L_c = 11.86$ mm, $g_a = 0.86$ mm, $g_b = 0.86$ mm.

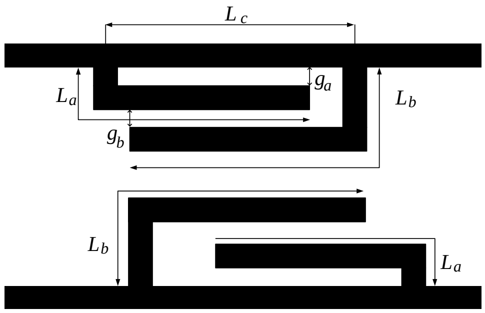

Figure 5: The structure of filtering network.

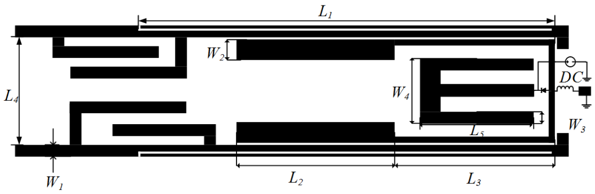

Figure 6: The structure of electrically tunable filter.

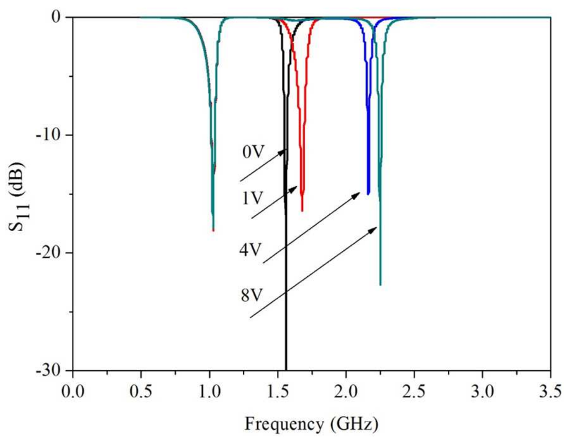

Figure 7: S_{11}-parameters of the tunable filter.

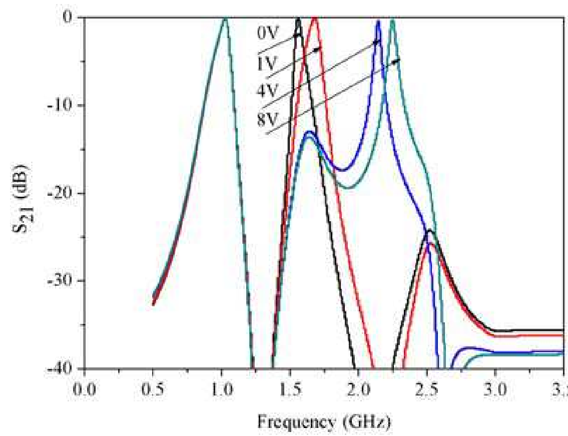

Figure 8: S_{21}-parameters of the tunable filter.

The results is shown in Fig. 7 and Fig. 8, the center frequency of first passband is fixed at 1.02 GHz with the relative bandwidth of 14.7%, the return loss is 18 dB and the insertion loss is 0.2 dB. The second passband are electrically tuned, when the value of the bias voltage across the varactor is changed. The center frequency can be tuned from 1.56 GHz to 2.25 GHz with the tuning range of 36.2%. The relative bandwidths almost remain unchanged. The return loss change from 16 dB to 30 dB and the insertion loss change from 0.2 dB to 0.8 dB. The filter proposed in this paper has a good harmonic suppression of -20 dB up to 3.5 GHz ($3.5f_1$).

At the whole process the center frequency of the second passband can be tuned from 1.56 GHz to 2.25 GHz, however, the center frequency of the first passband is fixed and maintained at 1.02 GHz. The reason is that the value of the bias voltage across the varactor can change the capacitance of the varactor, the input impedance of even model is changed, resonance frequency of even model is mainly determined by input impedance. But there is no influence on the resonant frequency of odd model. Fig. 7 and Fig. 8 show the relationship between frequency and the voltage. The four curves from left to right respectively corresponding to S_{11} of 0 V, 1 V, 4 V, 8 V. When the bias voltage varies from 0 to 1 V, the center frequency of the second passband changes from 1.56 GHz to 1.66 GHz. However, when the bias voltage changes from 4 to 8 V, the center frequency of the second passband changes from 2.15 GHz to 2.25 GHz. The amplitude of voltage changes different, but the center frequency remains the same which implies that the relation between voltage and moving of center frequency are not linear. This may be attributed to the performance of the varactor. According to the datasheet of SMV1247, when the bias voltage varies from 3 to 8 V, there is no linear relationship between value of capacitance and bias voltage, which is accordance to the previous analysis.

4. CONCLUSION

In this paper, a dual passband of wide stopband varactor tuned filter using SIRs is proposed. A varactor is loaded on the middle of the E-shaped resonators, by changing the value of the bias voltage, the center frequency of the second passband can be tuned while the center frequency of the first passband is fixed, which had been interpreted in the independence between even mode and odd mode. Feed coupled line is extended and bended to increases the coupling degree and reduce the insertion loss. Spurlines are added at the input and output coupling line is used to add zero between the two passband and to improve the selectivity of the filter. A filter network is added in the input and output coupling line to depress stopband. The center frequency of the second passband tuning from 1.56 GHz to 2.25 GHz with the tuning range of 36.2%. The return loss changes from 16 dB to 30 dB and the insertion loss changes from 0.2 dB to 0.8 dB. The center frequency of the first passband is fixed at 1.02 GHz. The return loss is 18 dB and the insertion loss is 0.2 dB. The harmonic suppression of −20 dB is up to 3.5 GHz ($3.5f_1$). The filter has a high tuning speed of nano seconds and is easy to realize a dual passband of wide stopband varactor tuned filter by the use of SIRs with centrally loaded elements. The filter proposed in this paper has great characteristics of harmonic suppression, low insertion loss, high return loss, wide tuning range, compared with other filters of the same frequency band. The filter can be useful for many dual passband applications, which is more demanding in near future.

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