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RECONFIGURABLE BANDSTOP FILTER WITH ADJUSTABLE BANDWIDTH AND CENTER FREQUENCY

K.-Y. Zhao, L. Li*, Q.-H. Wu, W.-Q. Xu, and Y.-M. Wang

School of Information, Zhejiang Sci-Tech University, Zhejiang 310018, China

Abstract—A bandstop filter with reconfigurable two-state center frequency and bandwidth is presented. The prototype of the proposed reconfigurable bandstop filter consists of one section of anti-coupled line short-circuited by an open low-impedance line. By introducing PIN diodes, this bandstop filter exhibits a lower stopband response centered at a lower frequency in the ON state, and a wider stopband response centered at a higher frequency in the OFF state. Filter using the proposed structure is designed, simulated and measured. The results confirm the designing method by showing a narrow stopband with the center frequency of 1 GHz and a wide stopband of 2.9 GHz bandwidth centered at 2.5 GHz respectively.

1. INTRODUCTION

Bandstop filter (BSF), as a crucial component of sending and receiving signals in telecommunication, plays the role of suppressing interference and inhibiting harmonics. The conventional method to design BSF may be generalized by two categories. One is to use the shunt open-circuited resonators that are quarter-wavelength long separated by transmission lines with the same length [1, 2]. The other is to use the capacitive gaps or a transmission line coupled to resonators. These methods are suitable for narrow stopbands normally. In order to meet the requirement of wide-band communication techniques, the photonic band gap (PBG) periodic structures [3, 4], the defected ground plane (DGS) structures [5–8] and signal interference technique [9, 10] are presented. As one of the deficiencies, however, all these BSFs are lack of the tunable central frequency and bandwidth and fail to meet

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* Corresponding author: Lin Li (lilin_door@hotmail.com).

the stringent requirement of modern multi-functional and cognitive systems. Consequently, the concept of reconfigurable BSFs has been attached greater significance. Some of these filters have reconfigurable structures like combline structure and tapped stubs tuned by PIN diodes or dumbbell-shaped coplanar waveguide [11, 12]. Previous reconfigurable BSFs most focus on tunable center frequency or the number of tuning statuses. However, BSFs with tunable stopband bandwidth are less commonly discussed [13–20].

Considering the reconfigurable BSF which can be tuned continuously, discretely or a combination of both [21], in order to avoid the deviation of control and to combine the continuously and discretely tuning states varactors and PIN diodes can be used. In this paper, a novel reconfigurable BSF is put forward based on a symmetrical coupled-line and PIN diodes which not only achieves tunable center frequency but also the bandwidth of the stopband. Compared with the existing reconfigurable BSFs [21–24], a wide and a narrow stopband are realized simultaneously which largely increases the adjustable feature. For example, in [22], though two stopband bandwidth are achieved, the tunable range of bandwidth is too limited, 6.94% for the low frequency state and 9.66% for the high frequency state. To this point, however, the BSF in this paper shows the tunable range of 8.5% for the ON state and 116% for the OFF state. Apart from this merit, DC low voltage control circuit is well designed to avoid the interference between DC and microwave signals and improve the stability and accuracy of the control.

2. FILTER DESIGN

Figure 1 shows the prototype of the proposed structure connected by a PIN diode below the coupled-line section. Based on the assumption

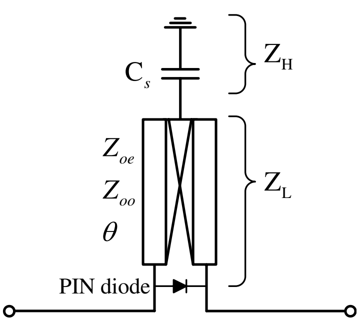


Figure 1. Prototype of the proposed reconfigurable BSF.

that the transmission lines are lossless, the on-resistance of PIN diode is negligible and all the discontinuity effects can be neglected, the whole structure can be separated into two serially connected sections: one is the coupled-line and a PIN diode as the lower network, and the other is an open transmission line stub equal to a short-circuited capacitance C_s as the higher network. Accordingly, the whole Z-matrix of the prototype is given by:

$$[Z_W] = [Z_H] + [Z_L] \tag{1}$$

where $[Z_W]$, $[Z_H]$, and $[Z_L]$ represent the impedance matrices of the whole, higher and lower sections respectively.

Regarding the characteristic of the PIN diode, the lower network consists of two states. For the first state, when the PIN diode is in the OFF state, the coupled-line is short circuited for a single end; for the second one, namely the ON state of the PIN diode the coupled-line is short circuited for both ends.

In the first state, impedance matrix $[Z^L_{\text{state1}}]$ can be calculated by using the even-odd mode analysis method as follows (assuming that the coupled-line section has the same even-odd mode electrical lengths θ):

$$Z^L_{11\text{state1}} = j\tan\theta(Z_{oe} + Z_{oo})/2 \tag{2}$$

$$Z^L_{21\text{state1}} = j\tan\theta(Z_{oe} - Z_{oo})/2 \tag{3}$$

where Z_{oe} and Z_{oo} are the even and odd mode characteristic impedances of the coupledline separately. Similarly, the Z-matrix of the whole structure for the second state is $[Z^L_{\text{state2}}]$:

$$Z^L_{11\text{state2}} = j\tan\theta Z_{oe}/2 \tag{4}$$

$$Z^L_{21\text{state2}} = -j\tan\theta Z_{oe}/2 \tag{5}$$

As for the higher network in Figure 1, the elements in $[Z_H]$ of the capacitance C_s are all the same and can be derived as:

$$Z^H_{mn} = \frac{-j}{\omega C_s}, \quad m, n = 1, 2 \tag{6}$$

From the relation between the S-matrices and impedance matrices, the transmission parameter can be obtained by [25]:

$$S_{21} = \frac{2Z^W_{12} Z_0}{(Z^W_{11} + Z_0)(Z^W_{22} + Z_0) - Z^W_{12} Z^W_{21}} \tag{7}$$

Obviously, transmission zeros occur at f where $S_{21} = 0$ or $Z_{21} = 0$. Therefore, for the first state the frequencies of the transmission zeros should satisfy the following equation derived from (3) and (6):

$$\tan\theta(Z_{oe} - Z_{oo})/2 = \frac{1}{\omega C_s} \tag{8}$$

Since the center frequency of the BSF is decided by two cut-off frequencies which are closely related to the positions of transmission zeros and the attenuation values of them, Equation (8) not only gives the positions of the transmission zeros but also a constant center frequency in the first state.

Based on the same method, for state 2, the equation is:

$$\tan\theta Z_{oe}/2 = \frac{-1}{\omega C_s} \tag{9}$$

Similarly, another center frequency in the second state is given by Equation (9). Comparing the two states, the center frequency of the proposed reconfigurable BSF becomes adjustable due to the deference of the number, the positions and the attenuation values of transmission zeros for the two states.

Since the bandwidth of the stopband is largely depended the number of the transmission zeros of which the positions are derived from (8) and (9), the reconfigurable bandwidth feature can be proved by simulating the same model with diverse parameters. Figure 2 and Figure 3 show the relation between the transmission zeros and the proposed structure with varying capacitances in state 1 and state 2 respectively. As illustrated in Figure 2(a), when the PIN diode is OFF in state 1, the reactance curve of the lower part is X_L and the higher part is X_H. There are three intersections between X_L and X_H within the range of 0 to 5.0 GHz through the stopband which means that three transmission zeros will be located through the stopband at

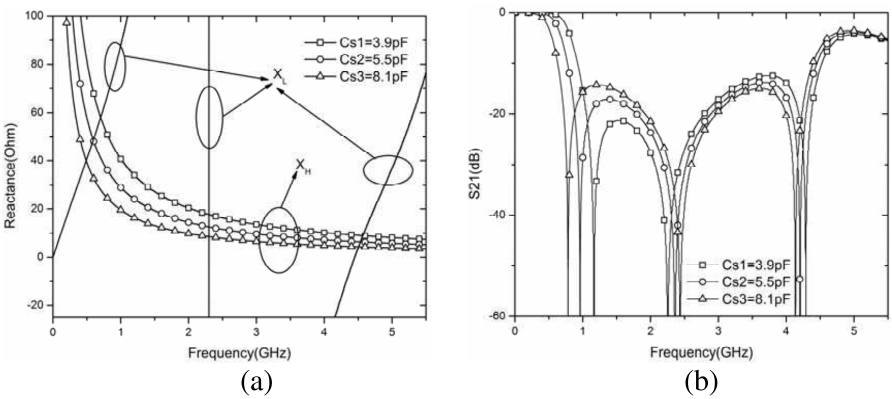
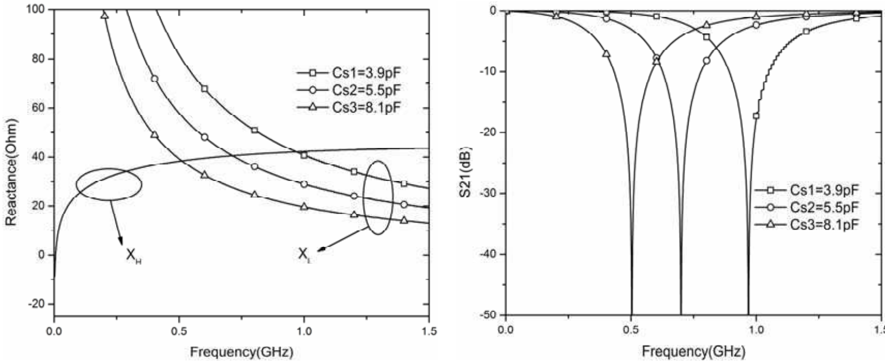


Figure 2. State 1, the proposed structure with different capacitive loads. (a) Pictorial reactance descriptions. (b) Simulated S-parameter with the following electrical parameters: $L_1 = 20.1$ mm, $W_1 = 0.2$ mm and $S_1 = 0.2$ mm.



(a) (b)

Figure 3. State 2, the proposed structure with different capacitive loads. (a) Pictorial reactance descriptions. (b) Simulated S-parameter with the following electrical parameters: $L_1 = 20.1\,\text{mm}$, $W_1 = 0.2\,\text{mm}$ and $S_1 = 0.2\,\text{mm}$.

the same frequencies of the intersections. The predicted results are substantiated by the simulated responses in Figure 2(b). Neglecting the simulation errors, the transmission zeros are almost at the same frequencies of the proposed intersections. Moreover, the three zeros shift to upper frequencies as the capacitance value decreases, an easy method to modify the bandwidth of the wide stopband.

As the PIN diode is ON in state 2, the curves of the X_L and X_H are displayed in Figure 3. Based on the same analysis above, there is an intersection within the frequency of 0.5 GHz to 1.2 GHz for each pair of curves of X_L and X_H, which means a transmission zero occurs in the S-parameter of the proposed structure. Correspondingly, a narrow stopband is achieved in state 2.

3. SIMULATED AND MEASURED RESULTS

To verify the above designing method, a reconfigurable BSF is implemented on a 0.5 mm substrate with a relative dielectric constant of 2.65 for an experimental demonstration. The layout and photograph of the fabricated filter are showed in Figure 4. In order to control the signal flow a DC low voltage control circuit is represented. In this circuit, two Skyworks SMP1345-079LF PIN diodes with a low capacitance of 0.2 pF, a parasitic inductance of 0.7 nH, and a resistance of 3.5 Ω are used as switches. Correspondingly, two DC blocking capacitors are set in the coupled-line to avoid the interference between

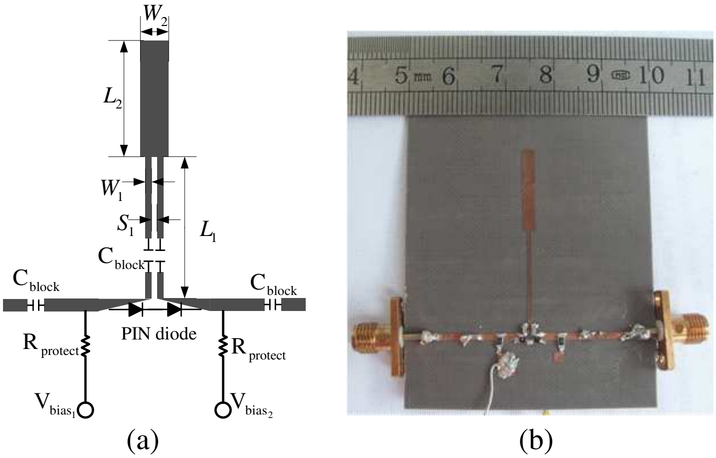


Figure 4. Fabricated reconfigurable BSF. (a) Layout. (b) Photograph. $L_1 = 21.1\,\text{mm}$, $L_2 = 18\,\text{mm}$; $W_1 = 0.2\,\text{mm}$, $W_2 = 2.5\,\text{mm}$, $S_1 = 0.28\,\text{mm}$.

DC and RF signal and another two capacitors near the ports are for tighter DC-RF isolation. Furthermore, the bias network including two $36\,\Omega$ protecting resistances is designed since the external DC voltage is 1.1 V and the current is less than 1 mA to turn on the PIN diode.

The simulated results performed by Ansoft HFSS and the measured results are displayed in Figure 5. From the results, there are the two different bandwidths of the stopband corresponding to the two states. For the narrow stopband the center frequency in the simulated curves is 1.0 GHz and the measured one nearly shows a duplication with the discrepancy of only 0.05 GHz. In the comparison of the wide stopbands the simulated result shows a 20 dB bandwidth with three transmission zeros from 1.3 GHz to 3.9 GHz. Because of the joint effect and the interference of DC unable to be blocked by the capacitances completely, the measured results reflect some deficiencies compared with the simulated results including the facts that the 20 dB stopband for state 1 ranging from about 1.5 GHz to 4.3 GHz is lack of a conspicuous transmission zero as showed in the measured results and also the attenuation of stopband is limited under 21 dB not as deep as the attenuation of the simulated stopband. However, the measured result is fully able to represent a wide stopband and such limitations can be overcome in large part by more skilled welding techniques and applying the capacitances of larger values. Summarily, the alteration of the center frequency as well as the bandwidth in the narrow and wide stopband is utterly in a position to demonstrate a novel feasible method of the reconfigurable BSF design.

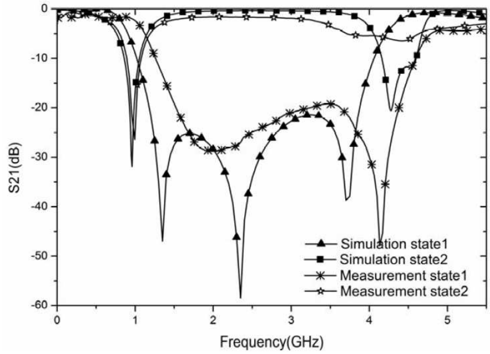


Figure 5. Simulated and measured S-parameters of proposed reconfigurable BSF.

4. CONCLUSION

A method of controlling the structure of the coupled transmission line according to the OFF and ON states of PIN diode is presented in this paper. The main feature of the proposed prototype is that tunable center frequency and bandwidth are achieved simultaneously. To apply this designing method, a reconfigurable BSF derived from the prototype is designed, fabricated and measured. The simulated results agree fairly well with the measured results. This newly proposed reconfigurable BSF can be used in a wide range of applications of microwave components especially with a rigid compact and multifunctional requirement.

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