# A Novel Reconfigurable Bandpass Filter Using Varactor-Tuned Stepped-Impedance-Stubs

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***Abstract*-A novel reconfigurable bandpass filter using varactor-tuned stepped impedance resonator (SIR) is introduced to achieve tunable central frequency and bandwidth. The varactor-tuned stepped impedance resonator structure consists of a stepped impedance with open or short-circuited stub and a varactor between the stubs. It's convenient to change the transmission zeros with the appropriate DC voltage controlling the values of varactor capacitors. In addition, the ratios between the two sections of SIRs can be easily changed to reformulate the resonant frequencies and then more design freedom of filter is obtained. The experimental results validate the design.**

## I. Introduction

With the rapid development of multiple frequency bands wireless communication system, the reconfigurable bandpass filters which can offer tunable center frequencies or bandwidths become necessary. Recently, many kinds of reconfigurable filters were reported. A lot of design approaches have been developed. For example, a new switching structure or resonator is proposed to realize reconfigurable center frequency[1]. However the insertion loss suffers from deterioration caused by complex structures. In [2], the bandwidth is adjusted with the assistance of varactors, and the position of transmission zeros is tuned by changing the DC voltage upon varactors. Nowadays, filters based on PIN diodes could switch the operating frequencies band between UWB and wireless LAN readily [3][4]. However, the designs discussed above provide a single method to achieve reconfigure center frequencies or bandwidths, independently.

In this paper a new reconfigurable filter using SIR structures and varactors is proposed. Center frequency and bandwidth are reconfigurable with similar structures in the design. The paper is organized as follows. Section II describes the theory of the proposed SIR structures and introduces the design of the reconfigurable SIR filter. And in Section III the experimental data are shown and compared with the simulation results. Finally, conclusions are given in Section IV.

## II. Reconfigurable Filter Designs

### A. *short-circuited SIR with varactors*

Fig.1.gives the general structure of a short-circuited

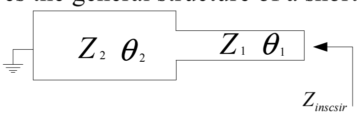


Fig. 1 The general structure of a short-circuited SIR

SIR, the input impedance of Fig. 1 can be derived from the following equation:

$$Z_i = jZ_1 \frac{Z_1 \tan\theta_1 + Z_2 \tan\theta_2}{Z_1 - Z_2 \tan\theta_1 \tan\theta_2} \tag{1}$$

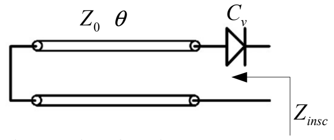


Fig. 2 Short-stubs of a microwave resonant structure

The input impedance corresponding to the structure displayed in Fig.2, is obtained from (2), and the transmission zero can be expressed as (3)

$$Z_{insc} = \frac{1 - \omega C_v Z_0 \tan\theta}{j\omega C_v} \tag{2}$$

$$1 - \omega C_v Z_0 \tan\theta = 0 \tag{3}$$

Where $C_v$ , $\omega$ , $Z_0$ and $\theta$ are the variable capacitance attributed to the varactor, the angular resonant frequency, the characteristic impedance, and the electrical length of the stub, respectively. Equation (3) indicates that the angular resonant frequency $\omega_0$ varies as $C_v$ changes, when $Z_0$ and $\theta$ are fixed.

As demonstrated above, the resonant structures shown in Figs. 2 induce tunable transmission zeros. However, regarding the realization of a reconfigurable filter, a relatively complicated tunable resonator configuration (Fig.3) is employed.

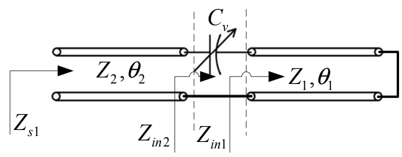


Fig. 3 Short-circuited SIR with a varactor

The input impedance $Z_{S1}$ of the whole circuit showed in Fig. 3 is given by Equation (4). Next, the corresponding S-parameter of this microwave network can be expressed as Equation (5).

$$Z_{S1}(\omega) = \frac{S(\omega)}{M(\omega)} = jZ_2 \frac{(Z_1 \tan\theta_1 + Z_2 \tan\theta_2)\omega C_v - 1}{(Z_2 - Z_1 \tan\theta_1 \tan\theta_2)\omega C_v + \tan\theta_2} \tag{4}$$

$$S_{21}(\omega) = \frac{1}{1 + Z_{S1}/2Z_0} = \frac{1}{1 + S(\omega)/2Y_0 M(\omega)} \tag{5}$$

And $Z_0$ is the characteristic impedance of the transmission line in shunt with the two varator-tuned resonant structures. Here, the transmission zeros are obtained by imposing S(ω)=0, whereas the transmission poles are obtained by M(ω)=0. It is shown that the capacitance of the varactor and the tunable transmission zero location are expressed as (6) and (7). Specifically, Figure 4 shows the variation of the zero/pole location with respect to the varactor capacitance.

$$C_v(\omega) = \frac{1}{Z_2\omega + Z_1\omega\cot\theta_1} \tag{6}$$

$$C_v(\omega) = \frac{\tan\theta_2}{Z_2\omega - Z_2\omega\cot\theta_1\tan\theta_2} \tag{7}$$

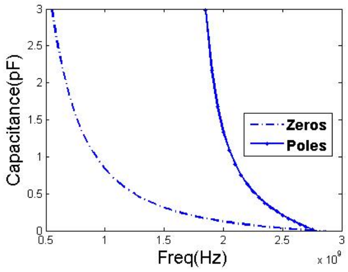


Fig. 4 The location of the transmission zeros and poles with respect to the capacitance of varactor

Based on the discussion above, a simple filter model is achieved in Fig.5, and the simulation results are displayed in Fig.6.Table I gives the data of the tunable bandwidth changed with the variable capacitance.

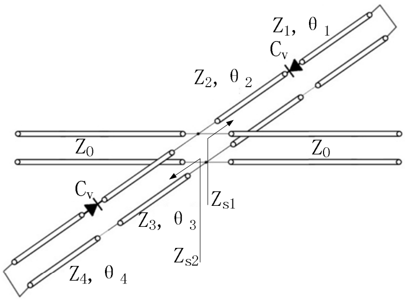


Fig. 5 Filter structure based on short-circuited SIRs with varactors

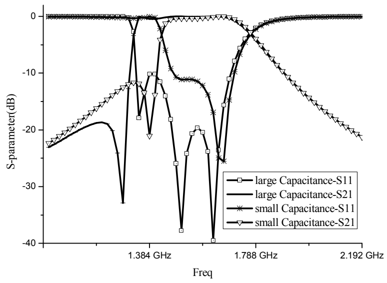


Fig. 6 Simulation results on filter structure showed in Fig.5.

TABLE.1 Simulation data on filter structure showed in Fig.5

| Capacitance | bandwidth | IL | RL |
|---|---|---|---|
| 3.6pF | 340MHz | ≤0.1dB | ≥10dB |
| 8pF | 440MHz | ≤0.4dB | ≥10dB |

It can be concluded that The FBW of filter structure based on short-circuited SIRs with varactors has a relative reconfigurability.

### B. *open-circuited SIR with varactors*

Fig.7.gives the general structure of an open-circuited SIR,

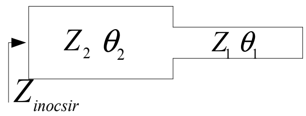


Fig. 7 The general structure of a short-circuited SIR

the input impedance of Fig. 7 can be derived from the following equation:

$$Z_{inoc} = jZ_1\frac{Z_1\tan\theta_1\tan\theta_2 - Z_2}{Z_1\tan\theta_1 + Z_2\tan\theta_2} \tag{8}$$

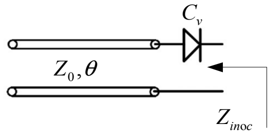


Fig. 8 Open-circuited SIR with a varactor

The input impedance of the structure shown in Fig.8, can be obtained from Equation (9), and then transmission zeros, can be evolved in (10), finally, the capacitance $C_v$ is expressed as Equation (11).

$$Z_{inoc} = \frac{\omega C_v Z_0 + \tan\theta}{j\omega C_v\tan\theta} \tag{9}$$

$$\omega C_v Z_0 + \tan\theta = 0 \tag{10}$$

$$C_v(\omega) = -\frac{\tan\theta}{\omega Z_0} \tag{11}$$

Obviously, the capacitance is negative in the case of $\theta \le 90^\circ$ .Under this condition, the capacitance is an inductor. the structure of Fig. 7 is reconstructed as a part of Dual Behavior Resonator (DBR) [6].

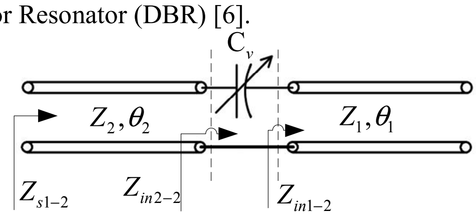


Fig. 9 Open-circuited SIR with a varactor

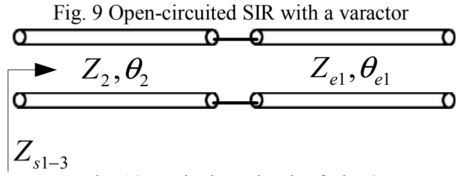


Fig. 10 Equivalent circuit of Fig. 9

$$\frac{Z_{e1}}{j\tan\theta_{e1}} = \frac{\omega C_v Z_1 + \tan\theta_1}{j\omega C_v\tan\theta_1} \tag{12}$$

With the aid of Eq. (12), an open-circuited SIR with a varactor shown in Fig.9 can be transformed to Fig 10, which is based on DBR.

## III. EXPERIMENTAL VERIFICATION

Fig. 11 and Fig.12 shows the transmission-line circuit of the BPF realized by the aforementioned design approach. The filter is simulated with Ansoft HFSS. $\theta = 36^\circ$ , $\theta = 54^\circ$ ,at the frequency 3.7GHz, The varactor SMV1405 manufactured by Skyworks[8] is used. Filters are fabricated on Rogers4003C and measured by Agilent network analyzer. All the results are presented in the following page.

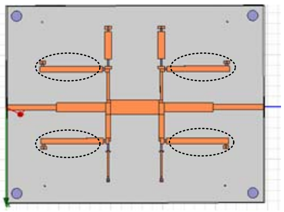

Fig. 11 Open-circuit structure simulation model

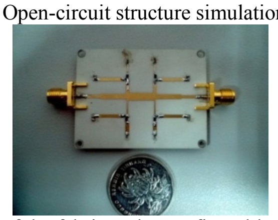

Fig. 12 Photograph of the fabricated reconfigurable BPF based on open-circuit structure

As a result, the following measured data are in highly agreement with the simulated data and Table II listed the center frequency and the maximum insertion loss (IL) and return loss (RL) at different DC bias.

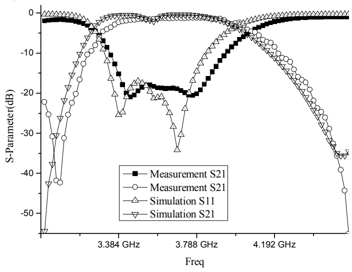


Fig. 13(a) Simulated and measured S-parameter the fabricated reconfigurable BPF

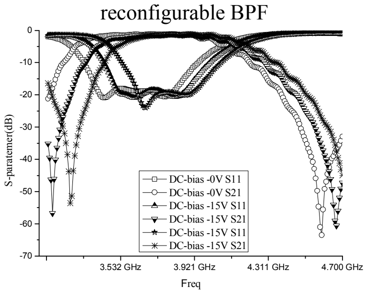


Fig. 14 (b) Measured S-parameter the fabricated reconfigurable BPF with DC-bias vary

TABLE II Measured S-parameter data the fabricated reconfigurable BPF with DC-bias vary

| DC bias | Center Frequency | IL | RL |
|---|---|---|---|
| 0V | 3.6GHz | ≤1.5dB | ≥18dB |
| 15V | 3.8GHz | ≤1.5dB | ≥18dB |
| 30V | 3.9GHz | ≤1.5dB | ≥18dB |

Additionally, another filter based on short-circuit structure discussed in section II, is fabricated. The measured S-parameters are in highly agreement with the simulation. Also, the final results reveal that the FBW can be adjusted from 3.1GHz to 3.7GHz.

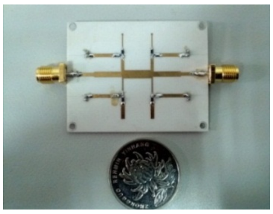

Fig. 15 Photograph of the fabricated reconfigurable BPF based on short-circuit structure

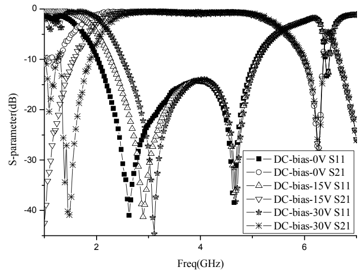


Fig. 16 Measured S-parameter the fabricated reconfigurable BPF with DC-bias vary

TABLE III Measured S-parameter data the fabricated reconfigurable BPF with DC-bias vary

| DC bias | bandwidth | IL | RL |
|---|---|---|---|
| 0V | 3.7GHz | ≤0.5dB | ≥14dB |
| 15V | 3.4GHz | ≤0.5dB | ≥14dB |
| 30V | 3.1GHz | ≤0.5dB | ≥14dB |

The Measurement of fabricated filters indicates that the structures discussed above can realize tunable center frequency and FBW.

## IV. Conclusion

Filters with similar structures are proposed and can achieve tunable bandwidths or center frequencies. The presented approach aims for the bandwidth and center frequencies reconfigurable realized with simple open and short stubs. The demonstrated BPFs have a relatively low insertion loss, relatively wider FBWs and center frequencies tuning range.

## Acknowledgment

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