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A NOVEL MICROSTRIP LC RECONFIGURABLE BANDPASS FILTER

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Abstract—In this paper, we propose and develop a novel reconfigurable bandpass filter based on microstrip LC resonators. The equivalent circuit model of the proposed filter is presented. The filter can be reconfigured by tuning the capacitance of the microstrip LC resonators. A reconfigurable bandpass filter based on semiconductor varactor diode loaded microstrip LC resonators with a tuning range of 2.496 GHz to 2.937 GHz, and a fractional bandwidth of 6.3% to 8.2% is demonstrated, and the measured insertion loss is 1.7 dB to 3.8 dB. The out-band rejection is better than 25 dB up to 10 GHz.

1. INTRODUCTION

Future multi-mode microwave systems require breaking through the traditional radio standard of the fixed pattern, i.e., central frequency [1, 2], bandwidth [3–5], and polarization [6–8], to increase spectrum utilization and expand the communication capacity. Microwave bandpass filters, which act as the channelizer in the RF frontend, are the key to constitute the air interface of radio systems. Therefore, electronically reconfigurable/tunable bandpass filters with varied passband will be essential components for future multi-mode wireless communication and radar systems.

Recently, since planar thin-film technologies are ideal platform for integrating electrical systems, several types of compact planar reconfigurable bandpass filters have been proposed. These filters including substrate integrated waveguide (SIW) filters [1, 5], half mode substrate integrated waveguide (HMSIW) filters [9–11], and microstrip resonators based filters [2, 12–15]. However, the above-referred reconfigurable filters are based on waveguide or distributed

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resonators. Research on the reconfigurable microstrip LC filter has been rarely reported. Microstrip LC filters exhibit small physical size and broad spurious-free frequency bands that typically affect distributed solutions, and it results in simple center frequency and bandwidth control as well [16].

In this paper, we report a novel microstrip LC bandpass filter and its application to reconfigurable filter design. Equivalent circuit model of the proposed filter is presented, and the reconfigurable mechanism of the filter response is analyzed. By using semiconductor varactor diode, an electrical reconfigurable microstrip LC bandpass filter is designed, fabricated and measured.

2. MICROSTRIP LC BANDPASS FILTER

Figure 1(a) shows the layout of the proposed bandpass filter based on magnetic and electric mix coupled microstrip LC resonators. As the electrical size of the resonators is small, the structures can be described by means of lumped elements. The proposed lumped-element equivalent circuit model for the bandpass filter is depicted in Figure 1(b). In the circuit model, the metallic vias are modeled as the inductor L_d, and M_d indicates the mutual inductance between the vias of the two resonators. The input microstrip connects to the resonator is modeled as L_s. The microstrip LC resonator is modeled as inductor L_r and capacitor C_r, and the magnetic coupling effect between the two resonators is denoted by M_r. The capacitor C_c indicates the parasitical electric coupling effect between the resonators.

To demonstrate this type of filter experimentally, the filter was fabricated on a 0.508 mm thick Rogers RT/Duroid 5880 substrate

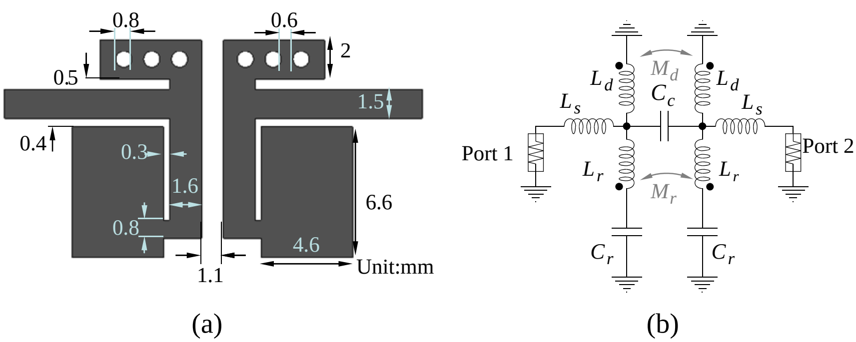


Figure 1. (a) Layout and (b) lumped equivalent circuit model of the microstrip LC bandpass filter.

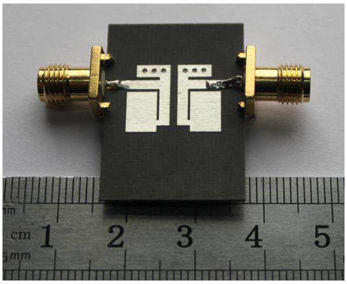


Figure 2. Fabricated bandpass filter based on mix coupled microstrip LC resonator.

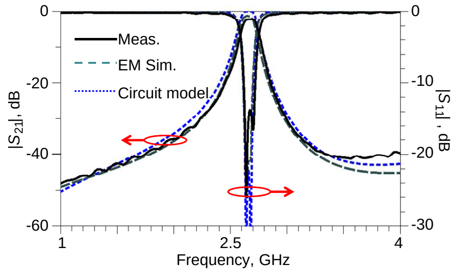


Figure 3. Simulated, measured and circuit model calculated S-parameters of the microstrip LC bandpass filter.

($\varepsilon_r = 2.2$, $\tan\theta = 0.0009$) using a copper etching process, as shown in Figure 2. The transmission responses for the filter are simulated and investigated by full-wave electromagnetics (EM) simulation. The S-parameters of the filter were measured with an Agilent E5071C vector network analyzer. The EM simulated and measured results are presented in Figure 3, and it shows that the filter has a measured central frequency of 2.68 GHz and a -3 dB bandwidth of 144 MHz. The insertion loss is approximately 2.2 dB, and the stopband rejection is better than 40 dB. By using the curve-fitting technology, we have extracted the parameters $L_s = 4.8$ nH, $L_d = 1.325$ nH, $L_r = 2.244$ nH, $C_r = 1.055$ pF, $C_c = 0.165$ pF, $M_r = -0.07$ nH, and $M_d = -0.005$ nH respectively from the equivalent circuit model network in Figure 1(b). The circuit model calculated results are shown in Figure 3, and it shows that the equivalent circuit model calculated results, EM simulated results and measured results match each other very well, therefore the equivalent circuit model is basically correct and is fully capable of explaining the frequency responses of the proposed microstrip LC structure.

3. TUNABLE MICROSTRIP LC FILTER

By symmetry of the lumped circuit model in Figure 1(b), the even- and odd-mode input impedances $Z_{in(e)}$ and $Z_{in(o)}$ are expressed as:

$$Z_{in(e)} = j\omega L_s + j\omega\left(L_d + M_d\right) \left\| \left[j\omega\left(L_r + M_r\right) + \frac{1}{j\omega C_r}\right]\right., \tag{1}$$

$$Z_{in(o)} = j\omega L_s + j\omega\left(L_d - M_d\right) \left\| \frac{1}{j\omega 2C_c} \right\| \left[j\omega\left(L_r - M_r\right) + \frac{1}{j\omega C_r}\right], \tag{2}$$

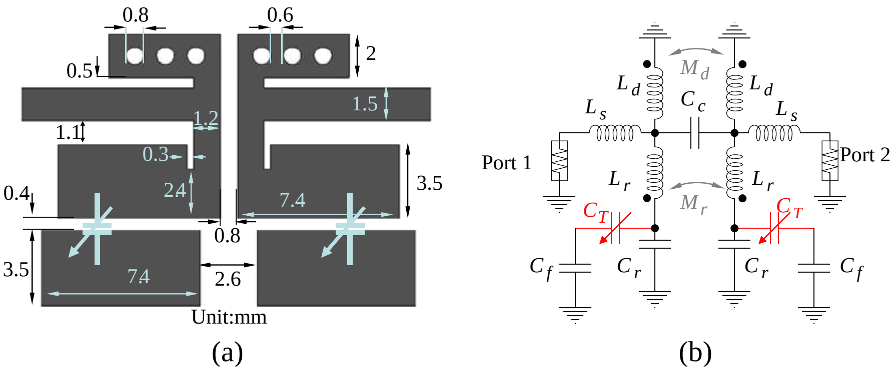


Figure 4. (a) Layout and (b) lumped equivalent circuit model of the reconfigurable microstrip LC bandpass filter.

The transfer function can be written as:

$$S_{21} = \frac{\left(Z_{in(e)} - Z_{in(o)}\right) Z_0}{\left(Z_{in(e)} + Z_0\right)\left(Z_{in(o)} + Z_0\right)}. \tag{3}$$

where, Z_0 is the impedance of the input port. It can be seen from (1), (2) and (3) that the transfer function S_{21} of the filter can be configured by tuning the capacitor C_r of the LC resonator. Since the top surface of the capacitor C_r is an opening structure, it will be easy to load tunable elements on the top surface. However, tuning the capacitor C_r directly will be very difficult in normal printed circuit process. Therefore a floating capacitor is used to connect a varactor to C_r in our design as shown in Figure 4(a). The lumped circuit model is developed in Figure 4(b). The floating capacitor C_f is used to connect the tunable capacitor C_T parallel with C_r, and the series capacitor of C_f and C_T is:

$$C_{equ} = \frac{C_f C_T}{C_f + C_T}. \tag{4}$$

Let R_T be the series resistance of the tunable capacitor C_T in the filter, and the component quality factor of C_{equ} can be written as [17]:

$$Q_{equ} = \frac{1}{\omega_0 C_{equ} R_T}. \tag{5}$$

where, ω_0 is the central frequency of the passband. Equation (4) shows that the tune ratio of C_{equ} increases while C_f increasing. However, it can be seen from (5) that, Q_{equ} decreases while C_f

increasing. Due to the series resistor R_T of the tunable capacitor C_T, there is a design tradeoff between tunable ratio (central frequency tunable range) and filter quality factor (insertion loss). Therefore, large tunable ratio capacitor with small serious resistance, i.e., high-Q MEMS capacitors [18], could be considered in the future to design reconfigurable filter with both wide tunable range and low insertion loss.

To demonstrate this type of reconfigurable filter, the filter is fabricated on Rogers 5880 substrate, as shown in Figure 5. Skyworks SMV1405 varactor diode is chosen as the tunable capacitor in our work, and two 82 nH inductors from Coilcraft are used as the RF choke. The single varactor capacitance is 0.63 pF and 2.67 pF at 30 V and 0 V reverse bias, respectively. The transmission responses for

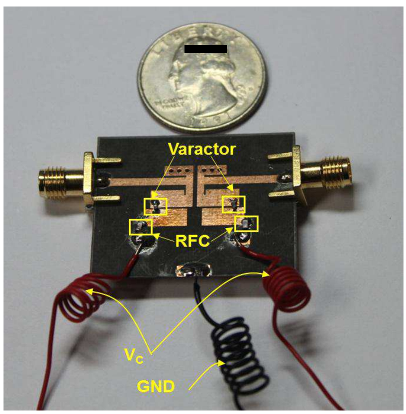
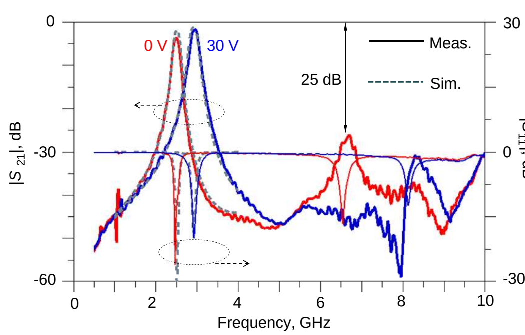
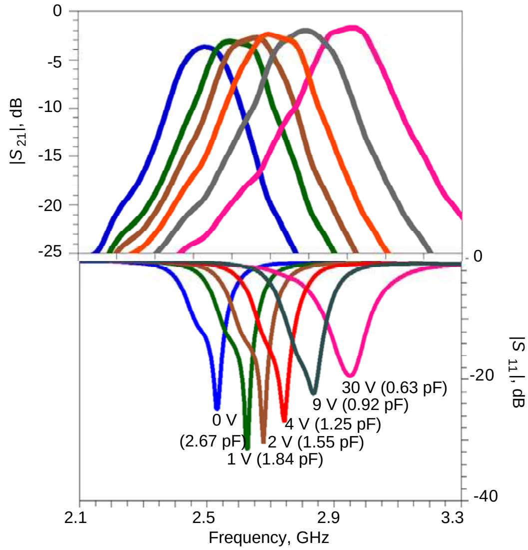


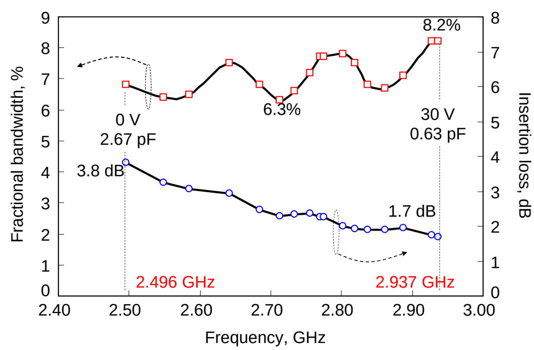
Figure 5. Fabricated reconfigurable microstrip LC bandpass filter based on semiconductor varactor diode.



(a)



(b)



(c)

Figure 6. The measured S-parameters of the reconfigurable microstrip LC bandpass filter. (a) The simulated and measured S-parameters under 0 V and 30 V bias. (b) The measured S-parameters under various bias voltages. (c) The fractional bandwidth and insertion loss versus the central frequency of the reconfigurable filter.

the filter were simulated and investigated by full-wave EM simulator and Advanced Design System (ADS), and Figure 6(a) presents the simulated and measured results at 30 V and 0 V reverse voltage. The out-band rejection is better than 25 dB up to 10 GHz.

The measured S-parameters under various reverse voltages are shown in Figure 6(b), and it shows that $|S_{11}|$ is below $-20\,\text{dB}$ in the tuning range. The reconfigurable characters are summarized in Figure 6(c). When 0 V to 30 V bias voltage is employed, the center frequency of the filter varies from 2.496 GHz to 2.937 GHz, the fractional bandwidth varies from 6.3% to 8.2%, and the insertion loss varies from 1.7 dB to 3.8 dB. From the measured results in this section, the proposed reconfigurable microstrip LC filter is successful demonstrated, and the filter topology is simple to implement. The reconfigurable microstrip LC filter can be good channelizer for multi-mode/multi-frequency band radio systems.

4. CONCLUSION

We have reported the development of novel microstrip LC bandpass filter and reconfigurable bandpass filter. Lumped equivalent circuit models are developed, and the reconfigurable mechanism is studied. A 2.496 GHz to 2.937 GHz reconfigurable filter with an insertion loss of 1.7 dB to 3.8 dB and a fractional bandwidth of 6.3% to 8.2% is demonstrated. The out-band rejection is better than 25 dB up to 10 GHz. Semiconductor varactor diode has been adopted in our work to design the reconfigurable filters, other low loss tunable elements, i.e., RF MEMS capacitor, switch, and PIN diode, can be used in future to reduce the insertion loss and increase the frequency tunable range. Multi-layer technologies, i.e., LTCC, can be used to reduce the size of the filter. Therefore, the proposed microstrip LC reconfigurable filter is a more practical reconfigurable channellizer.

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