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A novel dual-band tunable notch filter with controllable center frequencies and bandwidths

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ABSTRACT

This article proposes a new dual-band tunable bandstop filter. This tunable filter is composed of two separate parts, the transmission line, and coupled stubs that each connect to three varactors. The center frequency and bandwidth in each band can be controlled individually. Moreover, the LC equivalent circuit of the proposed filter is calculated, and the results are simulated. In the proposed filter, the simulations show that the first stopband can be tuned in a frequency range from 1.2 to 1.9 GHz with 10-dB absolute bandwidth 310 ± 30 MHz, whereas the second stopband varies from 2.5 to 3.3 GHz with the 10-dB absolute bandwidth 720 ± 20 MHz. These two stopbands can also be tuned independently. Furthermore, the bandwidth of each fixed center frequency can be changed easily. The fabricated proposed filter validates the simulation results. The compact filter has an effective size of $9 \times 27.5\,\text{mm}^2$.

1. Introduction

Bandstop filters have certain important roles in wireless communication systems because these filters generally are used to reject unwanted spurious and interferences signals [1]. Radio frequency (RF) tunable filters are more interesting issues for reducing the size, cost of fabrication, and complexity of multiband systems. Different methods have been introduced for tuning such as Yttrium-iron-garnet (YIG) [2], RF MEMS [3–5], and varactor diode [6–9]. Because of its high tuning speed, low cost, and compact size, the varactor diode has recently attracted much attention in tunable filter design [10,11].

Dual-band bandstop filters are mainly used for separating two stopbands. In addition, these filters can diminish the effects of double-sideband spectrum regrowth around the desired signals in the mixer and power amplifier. Many researchers propose various methods for tunability of the center frequency [9–11]. Some efforts are made in the tunability of bandwidth with fixed center frequency [12] and others concentrate on the simultaneous tunability of bandwidth and center frequency [4]. While the tunable dual-band bandstop filters are more attractive in many RF applications [13,14], independent control on the center frequency and bandwidth of each band receives much interest.

Tunable dual-band bandstop is presented in this paper. By tuning the coupling coefficient and the length, respectively, the center frequency and bandwidth of the each band can be individually controlled. This paper is organized as follows: Section 2 presents the equivalent LC circuit model for a new tunable dual-band bandstop. Theoretical analysis of odd- and even-mode admittance is done in Section 3. The proposed filter with simulation and measurement results are demonstrated in Section 4. Finally, Section 5 provides the conclusion.

2. Equivalent circuit

Fig. 1 illustrates the LC equivalent circuits of the single transmission line and coupled line. The values of inductors and capacitors in the LC circuit model are calculated as below [15–17]:

$$L_s = \frac{Z_s \sin\left(\frac{2\pi}{\lambda_g} l_s\right)}{\omega} \tag{1}$$

$$C_s = \frac{\tan\left(\frac{\pi}{\lambda_g} l_s\right)}{\omega Z_s} \tag{2}$$

$$C_g = \frac{(Z_{oe} - Z_{oo}) \tan\left(\frac{2\pi}{\lambda_g} l_c\right)}{2\omega Z_{oe} Z_{oo}} \tag{3}$$

$$C_p = \frac{\tan\left(\frac{2\pi}{\lambda_g} l_c\right)}{\omega Z_{oe}} \tag{4}$$

In our derivation, stands for the characteristic impedance, while l_s

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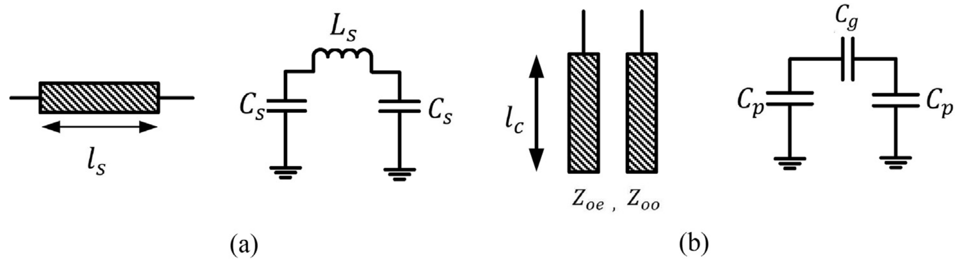

Fig. 1. The equivalent LC model of (a) the single transmission line (b) coupled lines.

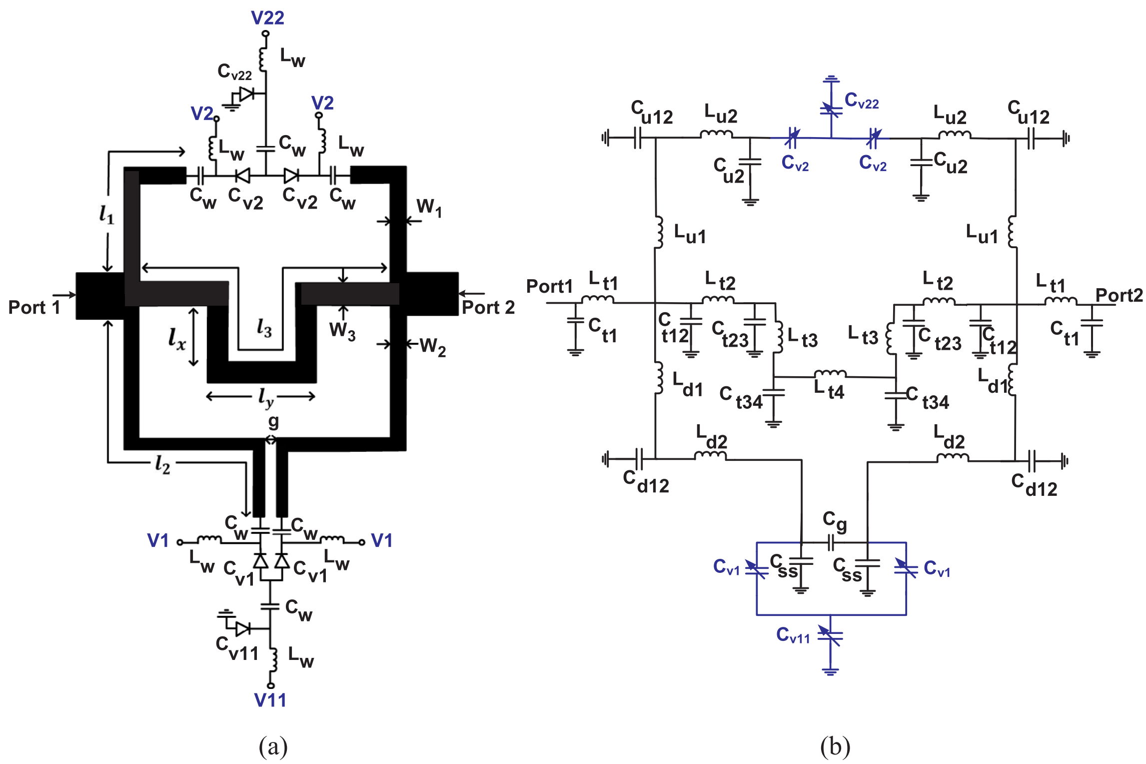

Fig. 2. (a) Layout of the proposed filter and (b) the LC equivalent circuit.

Table 1
LC equivalent circuit values of the proposed dual stopband filter (Units: C, pF; L, nH).

	L_{t1}	C_{t1}	C_{t12}	L_{t2}	C_{t23}	L_{t3}	C_{t34}	L_{t4}	L_{d1}	C_{d12}	L_{d2}
Values	3	0.5	2	0.56	0.1	0.6	0.01	2	3.8	0.2	3.7
	C_g	C_{ss}	L_{u1}	C_{u12}	L_{u2}	C_{u2}					
Values	0.0	0.6	2.4	0.15	1.3	0.1					

and λ_g denote the length of the microstrip line and the guided wavelength, respectively. Here, ω is the center of angular frequency, Z_{oo} and Z_{oe} are the odd- and even-mode impedance of the parallel coupled microstrip line with a length of lc. Fig. 2(a) shows the structure of the proposed dual-band microstrip bandstop filter, where six capacitors (varactors) are connected to the end of the resonators.

$$C_{t12} = C_{t1} + C_{u1} + C_{t2} + C_{d1}, \quad C_{t23} = C_{t2} + C_{t3}, \quad C_{t34} = C_{t3} + C_{t4},$$

$$C_{d12} = C_{d1} + C_{d2}, \quad C_{u12} = C_{u1} + C_{u2}, \quad C_{ss} = C_{d2} + C_s$$

Fig. 2(b) also shows the equivalent LC circuit of the proposed filter. The values of the L_{u1}, L_{u2} are the inductances and C_{u12}, C_{u2} are the capacitances rises from modeling the l_1 length. L_{d1}, L_{d2} are the inductances and C_{d12}, C_{d34} are the capacitances of the transmission line with l_2 length. L_{t2}, L_{t3}, L_{t4} are the inductances and C_{t12}, C_{t23}, C_{t34} are the capacitances of the transmission line with l_3 length. Here, C_g is the coupling capacitor between two stubs and $C_{ss}$is the sum of equivalent capacitances of metal–insulator–metal (MIM) and shunt capacitances of the transmission line.

Additionally, Table 1 tabulates the values of the LC equivalent circuit in Fig. 2(b).

3. Formulation

For analyzing the proposed structure, the method of odd- and even-mode resonances are shown in Fig. 3(a) and (b), respectively. In these figures, Y is the characteristic admittance and θ is the electrical length. The input admittances for odd- and even-mode equivalent are

$$Y_{ino} = j\left(Y_{u11}\frac{\omega C_{x2o} + Y_{u11}\tan\theta_1}{Y_{u11}-\omega C_{x2o}\tan\theta_1} + Y_{d11}\frac{\omega C_{x1o} + Y_{d11}\tan\theta_2}{Y_{d11}-\omega C_{x1o}\tan\theta_2} - Y_m\cot\theta_3\right) \tag{5a}$$