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Microstrip dual-band bandpass filter with independently tunable passbands using varactor-tuned stub loaded resonators

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ABSTRACT

In this paper, a dualband bandpass filter with independently tunable passband is proposed. Two half-wavelength resonators with shunt stub have been placed side by side, fed with a common input-output microstrip line to achieve the individual tunability without affecting other passband. For tuning resonance frequency, varactor diodes are used at the ends of the half wavelength resonators and also at the end of the shunt stubs. Proper shunt stub length and width are derived numerically in such a way that only one control voltage is required in each passband. Measured results show that lower passband can be tuned in a frequency range from 1.78 to 1.96 GHz, whereas the upper passband varies from 2.27 to 2.39 GHz individually. H shaped DGS is integrated below the input-output feed lines to suppress higher order harmonics up to 21 GHz with more than 19 dB attenuation.

1. Introduction

Tunable multiband bandpass filter is very essential component for a modern transceiver system such as cognitive radio due to size and cost reduction. Recent works for tunable bandpass filter have been concentrated on center frequency tuning with constant bandwidth [1–4] as well as bandwidth control [5–7] and tunable bandwidth with a fixed center frequency [8–10]. Tunability is achieved by integrating varactor diodes into the filter structure, but it is prone to limit the frequency tuning range. Dual band tunability is an option for widening the frequency range. Few tunable dual band filters have been proposed recently [11–18]. In [11], two open loop microstrip resonators centrally loaded with two varactor diodes have been used to tune the 2nd passband with fixed first band. Similarly, two stepped impedance resonators [12], Defected Ground Structure (DGS) [13] with varactor diodes are proposed for controllable second pass band keeping first band fixed. Recently new research has been done to control independently two passbands [14–17]. Two pairs of quarter-wavelength transmission lines along with two bandstop structures are implemented in [14]. In [15] two pairs of varactor diodes connected back to back at the end of two coupled center-loaded split ring tunable resonators are proposed for tuning both passband independently. Two tri-mode stub-loaded stepped-impedance resonators (SL-SIRs) of different dimensions [16], two different dual mode resonators with common input / output line [17] are used for dual band tunability. For tuning each band, two d.c. control voltages and three varactors are required in [16,17]. To minimize the number of control voltage, a novel structure is proposed in [18] where only one d.c voltage was used to control each passband. Recently few tunable filters are designed based on tunable metasurfaces [19,20]. However, the miniaturization of these band-pass filters [11–20] are required for compact wireless system applications. In [21–23], miniaturized metamaterial-inspired bandpass filters are introduced.

In this paper, only one d.c voltage and three varactor diodes are used to tune each passband that reduces the circuits complexity and cost. Even and odd mode admittance is analyzed theoretically for the proposed filter. By solving numerically, the desired stub length and width are calculated keeping the values of all capacitances of a stub loaded resonator same, so that only one voltage is required to tune one passband. Finally, harmonics are suppressed in a wide frequency range by using DGSs at input and output feed lines. In [24,25], the filters are integrated with DGS for harmonics suppression in a wide frequency range. The paper is organized as follows: In Section 2 detailed theoretical analysis of even and odd mode admittance has been carried out. Final proposed design with simulation results are presented in Section 3. The paper is concluded in Section 4.

2. Theoretical even-odd mode analysis

The proposed structure of the filter is shown in Fig. 1. Common input and output feed lines are used for two stub loaded resonators having different stub and resonator lengths. Each resonator

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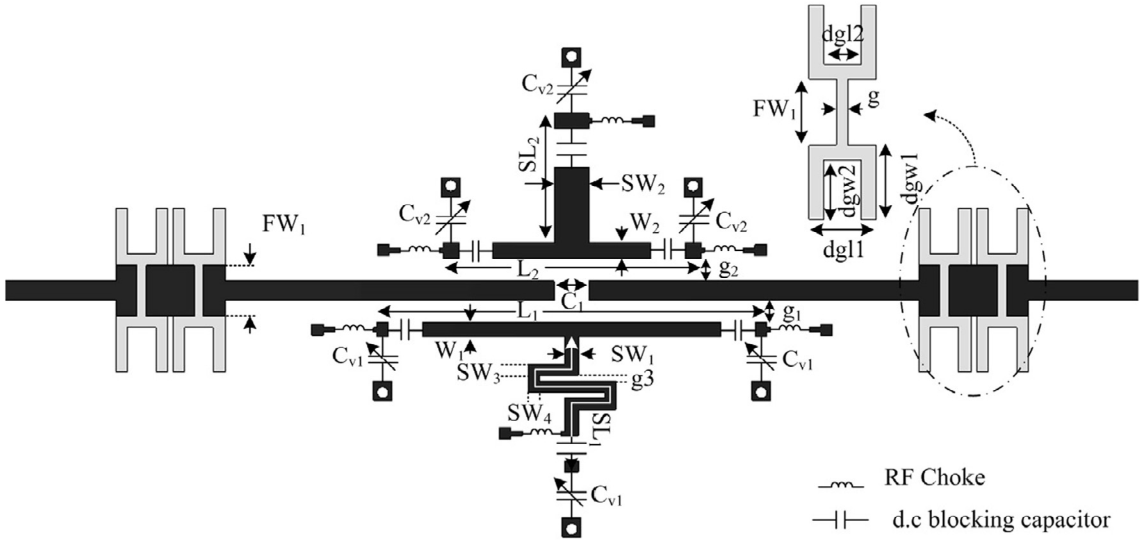

Fig. 1. Schematic structure of the tunable dual-band bandpass filter.

consists of three varactor diodes. Stub is loaded by one varactor diode and other two are connected at two ends of the resonator.

The basic structure of the proposed resonator is shown in Fig. 2. Two identical varactor diodes C_{V1} are connected at the end of uniform transmission line having characteristic admittance Y_1 and length L_1. Open stub is connected at the center of the resonator with characteristic admittance Y_2 and length L_2 followed by a varactor diode C_{V2} as shown in Fig. 2(a). Due to the symmetry of the structure, even-odd mode analysis can be applied in this structure to study the even-odd mode admittance and to find out the capacitance of the varactor for the even and odd mode resonant condition. Equivalent odd and even mode equivalent circuit is shown in Fig. 2(b), (c) respectively.

For odd-mode excitation, input admittance can be expressed as

$$Y_{in,odd} = j(wC_{V1} - Y_1 \cot\theta_1) \tag{1}$$

From Eq. (1) assuming $Y_{in,\ odd} = 0$, capacitance C_{V1} can be calculated as

$$C_{V1} = \frac{Y_1}{2\pi f_{odd} \times \tan\left(\pi f_{odd} \times L_1/V_p\right)} \tag{2}$$

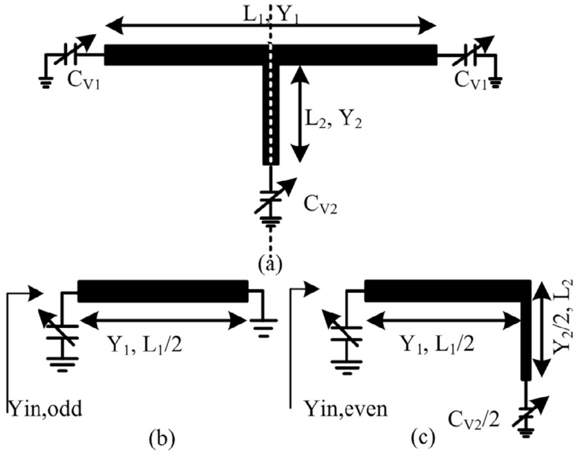

Fig. 2. (a) Basic Structure of proposed stub loaded resonator (b)Odd-mode equivalent circuit (c) Even-mode equivalent circuit.

Similarly, for even-mode excitation, even-mode input admittance can be derived as

$$Y_{in,even} = Y' + jwC_{V1} \tag{3}$$

where $Y' = Y_1 \frac{Y'' + jY_1 \tan\left(\frac{\beta L_1}{2}\right)}{Y_1 + jY'' \tan\left(\frac{\beta L_1}{2}\right)}$ and

$$Y'' = jY_2/2\left(\frac{wC_{V2} + Y_2 \tan\beta L_2}{Y_2 - wC_{V2} \tan\beta L_2}\right) \tag{4}$$

From (3) and (4) we can determine the capacitance C_{V2}, by taking $Y_{in,\ even} = 0$ as

$$C_{V2} = \frac{a+b}{c-d} \tag{5}$$

where

$a = Y_1 Y_2 (Y_2 \tan\beta L_2 + 2Y_1 \tan(\beta L_1/2))$
$b = wY_2 C_{V1}(2Y_1 - Y_2 \tan\beta L_2 \tan(\beta L_1/2))$
$c = w^2 C_{V1}(2Y_1 \tan\beta L_2 + Y_2 \tan(\beta L_1/2))$
$d = Y_1(wY_2 - 2wY_1 \tan\beta L_2 \tan(\beta L_1/2))$
$\beta = 2\pi f_{even}/v_p$

In Eq. (5) capacitance C_{V2} needed for even-mode resonance can be changed by modifying the length (L_2) and characteristic admittance (Y_2) of the stub keeping other parameters fixed. Fig. 3 shows that at a certain stub length and width, the ratio between two varactor diode capacitances will be equal to one. Thus we can use only one voltage source to tune the resonator in spite of two. It can also be concluded from Fig. 3 that with increasing stub impedance, the requirement of stub length is reduced to maintain the unit capacitances ratio.

Two different resonators with shunt stubs have been used in two separate dual-mode frequency bands. The reconfigurability is achieved by controlling three varactor diodes for each resonator. One single voltage source is applied across three varactors of a resonator. Total two voltage sources are needed to control two passband individually. Thus the optimal design reduces the overall circuit complexity compared to the related dual band reconfigurable filters [14,16,17].