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Compact dual-wideband bandstop filter using a stub-enclosed stepped-impedance resonator

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ABSTRACT

A compact, wide dual-band bandstop filter (DBBSF) based on a stub-enclosed stepped-impedance resonator (SE-SIR) is proposed. The second order filter is employed to obtain two transmission zeros in each stopband for better selectivity. The proportional tuning of both center frequencies is achieved by proportionately varying the electrical length of the enclosing stub with that of the high impedance section of the stepped-impedance resonator. Additionally, the second center frequency is tuned independently only by varying the electrical length of the enclosing stub. Two center frequencies at 4.7 and 6.64 GHz are reported, corresponding to the rejection of 35.1 and 26.23 dB and the fractional bandwidth of 31.02 and 23.93%, respectively at −3 dB. The size of the proposed filter is achieved to be $0.38\lambda_g \times 0.07\lambda_g$. The experimental results demonstrate its potential application in C-band communication systems.

1. Introduction

Modern microwave wireless communication systems are composed of bandstop filters in both the transmitter and receiver sections for the effective suppression of spurious signals. Dual-band bandstop filters (DBBSFs) are commonly embedded in high power amplifiers and mixers for suppressing unwanted double sideband signals, which reduce both the size and cost of the system. Because the resonators of DBBSFs resonate at stopband, they also possess low passband insertion loss and low group delay characteristics [1–3].

Various techniques were explored over the years for achieving DBBSFs. The dual stopband response was realized by applying two-step frequency variable transformation to the conventional LPF prototype [4], and the cross coupling technique used split ring resonators [5] for narrowband applications. Defected microstrip structure (DMS) [6–8] and defected ground structure (DGS) were implemented in [8] to obtain dual- and triple-narrowband bandstop responses; however, stability, reliability, integrity with the other devices and cost efficiency challenges occur with the implementation of DGS. A stepped-impedance resonator (SIR) is another effective way to achieve compact DBBSF as suggested in [1] and [9–11]. It is very difficult to individually control the center frequencies of the DBBSF as the change in dimension of the structure correspondingly affects both of the center frequencies by employing conventional type of SIR. A single-wideband bandstop filter was achieved by employing parallel-coupled transmission lines in [12], cross-coupled stubs [13] and open stub resonators in [14], however, realizing band-specific wideband DBBSF remains challenging.

This study proposes a compact DBBSF that employs stub-enclosed SIR (SE-SIR) to achieve two center frequencies in close vicinity with wide stopbands. The proposed design is explicitly analyzed by using relevant mathematical derivations and is compared with the conventional type SIR to explore the significance of the proposed design for obtaining wideband DBBSF. The application of a second order filter generates two transmission zeros in each stopband, which eventually enhances the selectivity of the filter. Additionally, the tuning characteristics evaluated here make the proposed DBBSF for its practical application in 5 GHz WLAN communication systems and other C-band applications.

2. Design synthesis and analysis

Conventionally, a non-uniform impedance technique in the form of SIR was adopted to obtain DBBSF, as shown in Fig. 1(a). The main limitation with this type of design is that the dimension modifications of the impedance sections eventually and uncontrollably impacts both of the center frequencies. However, the addition of an enclosing stub as shown in Fig. 1(b), i.e., a stub that encloses the high impedance section of the conventional SIR and is hence termed

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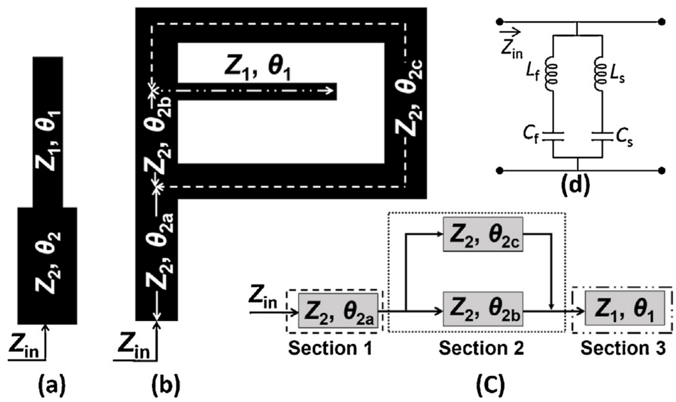

Fig. 1. Configuration for achieving DBBSFs: (a) conventional SIR; (b) topology of proposed SE-SIR; (c) simplified impedance modeling of (b); (d) all shunt connected series LC resonator.

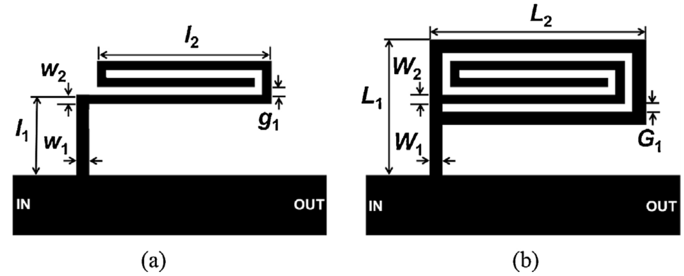

Fig. 2. Design of DBBSF: (a) using the conventional SIR technique with physical dimensions of $l_1 = 1.9$, $l_2 = 4.1$, $w_1 = 0.3$, $w_2 = g_1 = 0.2$; (b) proposed SE-SIR type DBBSF with physical dimensions of $L_1 = 3.2$, $L_2 = 5.1$, $W_1 = 0.3$, $W_2 = G_1 = 0.2$. All units are in mm.

as stub-enclosed SIR, makes it possible to achieve two fairly close center frequencies to apply in band-specific applications and can be tuned by appropriately varying the electrical length. So, this technique explores an extra degree of freedom in the design of bandstop filters, in which the conventional type of SIR is used to set the first center frequency (f_f), and the enclosing stub can be added with an appropriate length to match the second center frequency (f_s), as per the design requirements. The impedance model of the proposed SE-SIR is shown in Fig. 1(c).

To obtain the input impedance (Z_{in}) of the proposed first order filter, the design is partitioned into three sections: the first section consists of a stub with characteristic impedance (Z_2) and electrical length (θ_{2a}); the second section consists of parallel stubs including a portion of the conventional SIR with characteristic impedance (Z_2) and electrical length (θ_{2b}), which is in parallel to the enclosing stub with characteristic impedance (Z_2) and electrical length (θ_{2c}); the third section is similar to the high impedance section of the conventional SIR with characteristic impedance (Z_1) and electric length (θ_1), as shown in Fig. 1(c). It is apparent to evaluate the overall input impedance by cascading the ABCD matrix [15] of sections 1 and 2 and by terminating with high impedance section (section 3) of the proposed SE-SIR.

The ABCD matrix of section 1 is deduced as

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_a = \begin{bmatrix} \cos\theta_{2a} & jZ_2\sin\theta_{2a} \\ \dfrac{j\sin\theta_{2a}}{Z_2} & \cos\theta_{2a} \end{bmatrix} \quad (1)$$

The admittance matrix (Y_b) of section 2 in Fig. 1(c) is obtained as follows

$$Y_b = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix}_b = \begin{bmatrix} \dfrac{1}{jZ_2}(\cot\theta_{2b} + \cot\theta_{2c}) & \dfrac{j}{Z_2}(csc\theta_{2b} + csc\theta_{2c}) \\ \dfrac{j}{Z_2}(csc\theta_{2b} + csc\theta_{2c}) & \dfrac{1}{jZ_2}(\cot\theta_{2b} + \cot\theta_{2c}) \end{bmatrix} \quad (2)$$

The ABCD parameters obtained after cascading sections 1 and 2 are given by

$$\begin{aligned} A &= \frac{\sin(\theta_{2a}+\theta_{2b}+\theta_{2c}) + \sin\theta_{2a}(\cos(\theta_{2b}+\theta_{2c})-2)}{\sin\theta_{2b}+\sin\theta_{2c}} \\ B &= jZ_2\frac{\sin\theta_{2a}\sin(\theta_{2b}+\theta_{2c}) + \cos\theta_{2a}\sin\theta_{2b}\sin\theta_{2c}}{\sin\theta_{2b}+\sin\theta_{2c}} \\ C &= \frac{1}{jZ_2}\,\frac{\cos(\theta_{2a}+\theta_{2b}+\theta_{2c}) + \cos\theta_{2a}\left(\cos(\theta_{2b}+\theta_{2c})-2\right)}{\sin\theta_{2b}+\sin\theta_{2c}} \\ D &= \frac{\cos\theta_{2a}\sin(\theta_{2b}+\theta_{2c}) - \sin\theta_{2a}\sin\theta_{2b}\sin\theta_{2c}}{\sin\theta_{2b}+\sin\theta_{2c}} \end{aligned} \quad (3)$$

The overall input impedance (Z_{in}) of the composite SE-SIR is deduced as

$$Z_{in} = jZ_2\frac{Z_1\cot\theta_1(\sin(\theta_{2a}+\theta_{2b}+\theta_{2c}) + \sin\theta_{2a}(\cos(\theta_{2b}+\theta_{2c})-2)) - Z_2(\sin\theta_{2a}\sin(\theta_{2b}+\theta_{2c}) + \cos\theta_{2a}\sin\theta_{2b}\sin\theta_{2c})}{Z_1\cot\theta_1(\cos(\theta_{2a}+\theta_{2b}+\theta_{2c}) + \cos\theta_{2a}(\cos(\theta_{2b}+\theta_{2c})-2)) - Z_2(\cos\theta_{2a}\sin(\theta_{2b}+\theta_{2c}) - \sin\theta_{2a}\sin\theta_{2b}\sin\theta_{2c})} \quad (4)$$

At the resonance condition, $Z_{in} = 0$ such that

$$R_z = \frac{Z_2}{Z_1} = \frac{\cot\theta_1(\sin(\theta_{2a}+\theta_{2b}+\theta_{2c}) + \sin\theta_{2a}(\cos(\theta_{2b}\theta_{2c})-2))}{(\sin\theta_{2a}\sin(\theta_{2b}+\theta_{2c}) + \cos\theta_{2a}\sin\theta_{2b}\sin\theta_{2c})} \quad (5)$$

where R_z is the impedance ratio of low to high impedance section of the SE-SIR.

Eq. (5) reveals that the resonance of the proposed filter relies on different electrical lengths, θ_1, θ_{2a}, θ_{2b} and θ_{2c}, of the proposed SE-SIR in addition to impedances Z_1 and Z_2. Furthermore, it is believed that the above resonance condition would match the characterization of the dual-band resonance frequencies, ω_f and ω_s, defined by the input impedance, Z_{in}, of the composite series LC resonators shown in Fig. 1(d) as given by the following equation [1].

$$Z_{in} = \frac{j}{\omega}\,\frac{\sqrt{L_f L_s}(\omega^2-\omega_f^2)(\omega^2-\omega_s^2)}{\omega_s\sqrt{L_f C_s}(\omega^2-\omega_f^2) + \omega_f\sqrt{L_s C_f}(\omega^2-\omega_s^2)} \quad (6)$$

Based on the above analysis, a DBBSF is designed in the following two steps:

(i) Using a conventional SIR structure of Fig. 1(a), the first center frequency at 4.6 GHz was obtained. At this condition, the resonance can be achieved by ignoring the effect of enclosing stub length, θ_3, so that Eq. (5) will be modified to

$$R_z = \frac{Z_2}{Z_1} = \frac{\cot\theta_1(\sin(\theta_{2a}+\theta_{2b}) + \sin\theta_{2a}(\cos(\theta_{2b})-2))}{(\sin\theta_{2a}\sin\theta_{2b})} \quad (7)$$

The design of conventional SIR is shown in Fig. 2(a) having $Z_1 = 131.1\,\Omega$, $\theta_1 = 100.65^\circ$, $Z_2 = 112.83\,\Omega$ and $\theta_2 = \theta_{2a} \pm \theta_{2b} = 14.71^\circ$. This design specification also results the