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Full Length Article

Harmonic suppressed coupled stepped-impedance resonator based dual-band tunable bandpass filter

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ABSTRACT

In this paper, a tunable dual-band bandpass filter (BPF) based on a varactor-loaded coupled stepped-impedance resonator is presented. Transmission matrices techniques are employed to explain the working concept of proposed tunable BPF. For validating the proposed concept, a hardware prototype is fabricated and characterized. As per the measured results, when the center frequency of the lower band is tuning from 2.15 to 2.40 GHz, the upper band is fixed at 4.5 GHz; and when the center frequency of the upper band is tuning from 4.5 to 4.75 GHz, the lower passband almost remains constant at 2.25 GHz. Proposed tunable filter is capable of working at higher passband frequencies. Spurious harmonic suppression up to 15 GHz is demonstrated. Center frequency of dual-passband is tunable using only two dc control voltages.

1. Introduction

Reconfigurable devices find applications in cognitive radio (CR), software-defined radio (SDR), wideband radar, UWB wireless system and electronic warfare systems [1]. Because of its flexible response, the tunable filters are required in commercial and military RF applications. Reconfigurable filters also help in obtaining wideband coverage with minimized system size, cost and complexity. Multiband reconfigurable filters find application in carrier aggregation scheme and multiband CR/SDR which is crucial for advanced modern wireless and mobile communication system. It is challenging to obtain a multiband reconfigurable response due to limited degrees of freedom in terms of numbers and realizable values of design parameters.

A compact size reconfigurable bandpass filter (BPF) has been designed using coupled-octagonal defected ground structure [2]. A varactor-loaded half-wavelength ($\lambda_g/2$) slot-line resonator has been used for continuously tuning the center frequency of the passband of the filter [3]. A reconfigurable bandpass filter with independent bandwidth and center frequency control in a discrete manner using PIN diodes for antenna based systems has been presented [4]. A wide tuning range BPF has been reported based on Varactor-loaded hairpin line resonator [5]. Tunable filters based on the use of U-shaped resonators with several varactors connected to each of the resonators have been proposed [6]. Design of concurrent dual-band BPFs with tunable lower passband and fixed upper passband have been reported [7]. A dual-band tunable BPF with independently tunable dual passbands based on an asymmetric $\lambda/4$ resonator pair with shared via-hole ground has been presented [8]. A dual-band BPF with a tunable lower passband based on two quarter-wavelength resonators and one half-wavelength resonator has been proposed [9]. A dual-mode dual-band BPF with tunable lower frequency band while fixed upper band has been designed using varactor-loaded folded square loop resonator [10]. A simple and systematic method for designing reconfigurable combline filters with broad tuning ranges is described in [11]. Varactor-loaded capacitively stepped-impedance resonator based BPF for center frequency tuning has been demonstrated [12]. A tunable dual-band BPF composed of quarter-wavelength ($\lambda_g/4$) resonators and two bandstop structures has been presented [13]. A varactor-loaded tunable dual-band BPF with suppressed harmonics has been presented [14].

Tuning of passband center frequency of filter is demonstrated in [2,3,5,6,11,12,20,21], but these are not offering concurrent dual-band performance. In [7,9,10,18], only lower frequency band is tunable while upper frequency band is fixed. Currently, there are only a few reported works in open literature on independently reconfigurable multiband BPF. In [14], independent tuning of lower and upper frequency bands are not possible. Use of defected ground structure (DGS) for getting harmonic suppression characteristics may increase the design and fabrication complexity of

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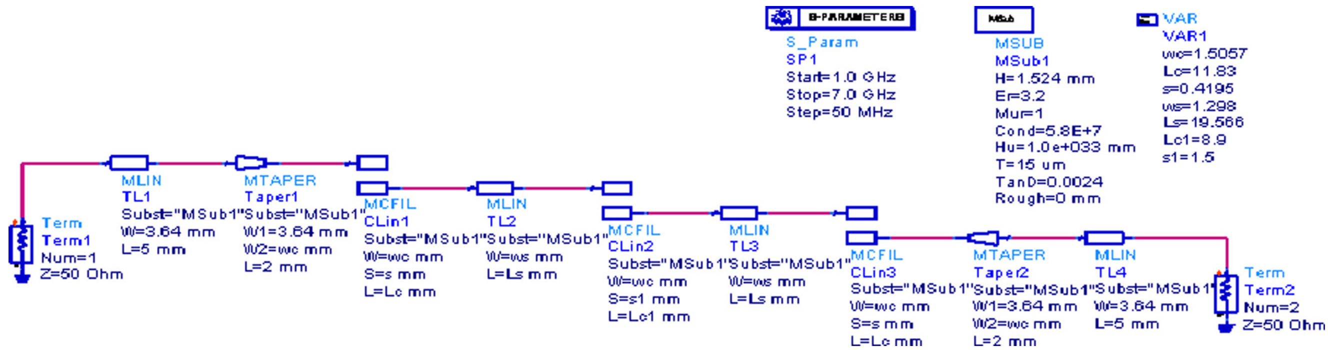

Fig. 1. ADS schematic circuit diagram of initial concurrent dual-band BPF.

the proposed tunable dual-band BPF [14]. Independent tuning of center frequency of dual-passband is reported in [8], but it does not offer the harmonic rejection characteristics. Tunable dual-band BPF, reported in [13], has increased design complexities and it uses 12 varactor diodes as tuning elements and four dc control voltages for biasing the diodes. In [19], the proposed tunable BPF is not capable to work for higher frequencies because of stringent constraint ([19], Eq. (7)) on filter's operating frequency in terms of available varactor diode's capacitance.

In this paper, a wideband harmonic suppressed reconfigurable dual-band BPF which is capable of working at higher passband frequencies is reported. Stepped-impedance resonator (SIR) is commonly used for shifting apart the higher order resonant modes [15–17]. We employed parallel-coupled SIR structure for obtaining wideband (>15 GHz) harmonic suppression characteristics with reduced design complexities. Varactor-loaded transformer with higher degree of design freedom is incorporated in the initial CSIR (coupled stepped-impedance resonator) based dual-band BPF for providing higher operating frequency tunability. Dual-passband is reconfigurable using only two dc control voltages. Design approach of proposed varactor-loaded transformer has been included in Section 2 of the paper. Measured results of reflection coefficient ($|S_{11}|$) and transmission coefficient ($|S_{21}|$) for various varactor capacitances have been included in Section 3 of the paper. Finally, the main conclusion of the work is highlighted in Section 4 of the paper.

2. Design approach of proposed varactor-loaded transformer

2.1. Initial bandpass filter circuit

Initially, a high performance dual-band bandpass filter (BPF) without loading any varactor diode is designed. A concurrent dual-band BPF based on microstrip parallel-coupled stepped-impedance resonator (SIR) is designed and simulated. Fundamental characteristics of different types of SIR's are systematically summarized in [15]. The coupling of two half-wavelength ($\lambda_g/2$) SIR is exploited to achieve the concurrent dual-band response. A dual-band response can be obtained by shifting higher order resonant modes of SIR at desired second band [17]. The approach of designing initial dual-band BPF is detailed in [16–17]. Fig. 1 shows the circuit diagram of initial BPF designed using ADS schematic tool.

Dual-band BPF is designed on a microstrip substrate with Substrate thickness (H) as 1.524 mm, dielectric constant (ϵ_r) as 3.2, and loss tangent (tanδ) as 0.0024. Simulated value of center frequency of lower passband is 2.25 GHz while that of upper passband is 4.75 GHz. The value of design parameters of initial filter structure is as follows: Input/output port impedances (Z_0) as 50-Ω, coupling line width (W_C) as 1.5057-mm, input/output coupled-line length (L_C) as 11.83-mm, interstage coupled-line length (L_{C1}) as 8.9-mm, input/output coupled-line spacing (S) as 0.4195-mm, interstage coupled-line spacing (S_1) as 1.5-mm, single line width (W_S) as 1.298-mm, and single line length (L_S) as 19.566-mm, respectively. Fig. 2 shows the simulated characteristics ($|S_{11}|$ and $|S_{21}|$) of initial dual-band BPF. Proposed varactor-loaded transformer will be incorporated in the initial filter structure for obtaining the tunable dual-band bandpass filtering response.

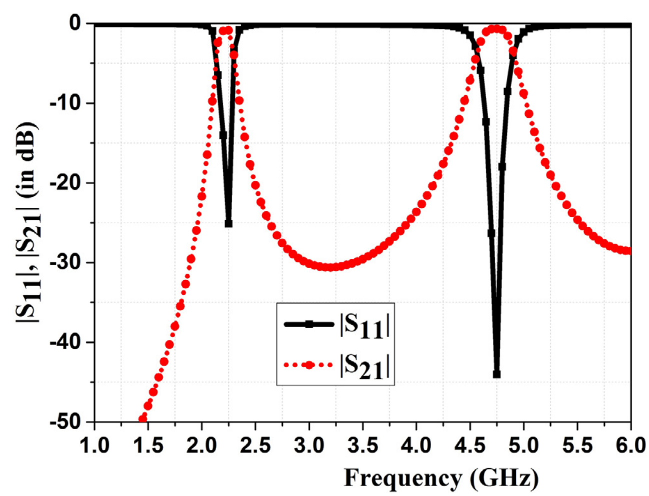

Fig. 2. Simulated characteristics for reflection coefficient ($|S_{11}|$) and transmission coefficient ($|S_{21}|$) of initial dual-band BPF.

2.2. Proposed varactor-loaded transformer

Fig. 3(a) shows the high impedance (high-Z) single microstrip line section of initial bandpass structure shown in Fig. 1. The characteristics impedance (line width) and electrical length (line length) of single line section at frequency f_1 are Z_S (W_S) and θ_S (L_S), respectively. Fig. 3(b) shows the varactor-loaded transformer used in [19] to obtain tunable dual-band response. For the tunable transformer shown in Fig. 3(b), the constraint on varactor capacitance in terms of operating frequency for tunable dual-band performance is represented by the following relation,

$$\frac{C_{VU}^2}{C_{VL}} + 2C_{VU} < \frac{\mathrm{Sin}\theta_S}{2\pi f_1 Z_S} \tag{1}$$

Using (1), the constraint on the value of C_{VU} in terms of operating frequency and C_{VL} is represented by (2).

$$C_{VU} < \sqrt{C_{VL}^2 + \frac{C_{VL}\mathrm{Sin}\theta_S}{2\pi f_1 Z_S}} - C_{VL} \tag{2}$$