Trisection Open-Loop Varacter-Based Tunable Filter for 5G Wireless Communications

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Abstract. In this manuscript, a very compact planar reconfigurable bandpass filter (BPF) operating from 3.4 to 3.8 GHz spectrum bandwidth for fifth-generation 5G wireless communications is proposed. The microstrip band-pass filter (BPF) employes three-ring resonators with 50 Ω transmission line impedances for input and output ports. The mutual coupling coefficients are controlled to achieve the required frequency response with three poles bandpass Butterworth properties. Varactor switch and biasing circuits are modeled to control the centre frequency in the required bands. The presented tunable filter is designed on Rogers RO3010 dielectric material with a relative permittivity of 10.2 and a very small size of $17\times5\times1.27$ mm^3. The introduced reconfigurable BPF is designed and optimized using CST tool.

Keywords: planar, band-pass, reconfigurable, frequency, Rogers.

1 Introduction

Radio frequency noise is an increasingly serious issue in modern wireless communication applications such as 5G and wide-band radar systems [1-18]. Microstrip band-pass filters are generally used to filter noise signals and unwanted frequencies in wireless communication applications [19], particularly in radio frequencies and microwave communications due to their effective rejection of spurious frequencies. Nowadays, 5G wireless communication technology is being considered for use in 700 MHz, 3.6 GHz and 26 GHz bands [20]. Band-pass filters are useful units in many 5G systems for rejecting unwanted signals. In addition, there are particular requirements for band-pass filters in such systems [21, 22]. A band-pass filter contains a number of coupled resonators, and the dimensions of the distributed elements and the number of resonators proposed defines the filter characteristics. Consequently, most microstrip filter miniaturization techniques seek to minimize one or other of these quantities [23-31]. A variety of structures and methods have been proposed for microstrip tunable filters such as combline, hairpin, parallel-coupled line, step impedance, and stub impedance [21-39].

A planar microwave tunable bandpass filter using a varactor diode is investigated for controlling a constant bandwidth [32]. Tuning the resonant frequency can be achieved simply by controlling the resonant frequencies for both the odd and even modes as there is not any coupling between these modes. In [33], a planar tunable filter is designed by using two varactor diodes to adjust two transmission zeros (TZs). The resonant frequency and the bandwidth of this filter are adjusted with a wide tuning range of about 590 MHz (1.5–2.1 GHz) by controlling the

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DC biasing voltage across to the varactor diodes. In [37], a compact reconfigurable microstrip filter with constant characteristics is presented. By controlling the DC biasing voltage of four varactor diodes, the designed filter is reconfigurable from 1.8 to 1.9 GHz with a 5% fractional bandwidth.

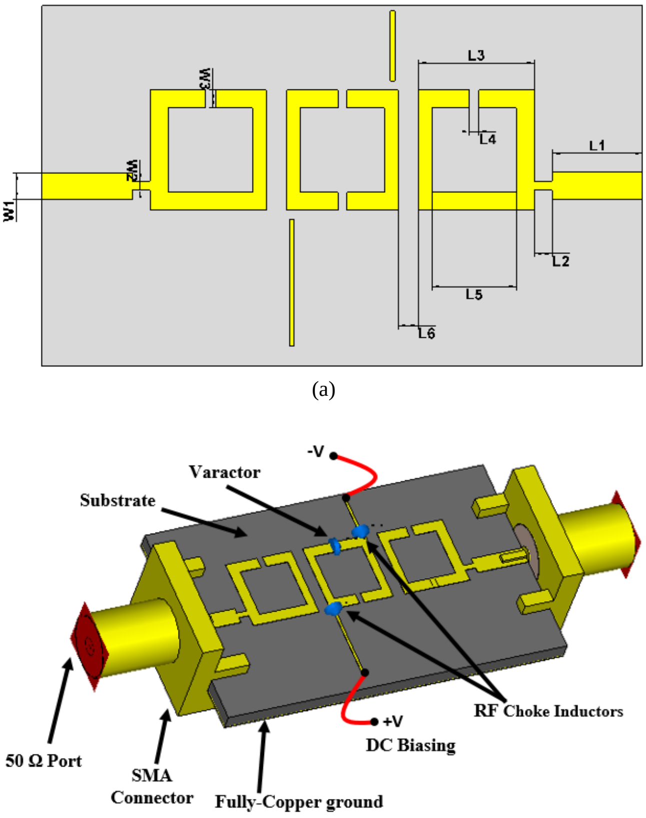
In recent years, many designs of reconfigurable microstrip filters have been proposed and investigated. Chen et al. [38] designed a second-order microwave reconfigurable filter with a compact size and constant bandwidth. Two varactor diodes are used to tune the resonant frequency between the higher and lower modes of operation with a range of 1.2 to 1.9 GHz and constant fractional bandwidth of 39 MHz. The properties of small size (0.06 λg × 0.27 λg), continuous reconfigurable capacity, simple design, and wide-ranging frequency made the designed filter suitable for the recent wireless communications. Ebrahimi et al. [39] proposed a notch tunable bandstop filter by using two varactor diodes. The designed second-order filter illustrates a continuous tuning range of the resonant frequency of 0.7–1 GHz with a compact structure of 0.15λg ×0.17λg size. Unlike the previous structures, the inductive coupling is obtained by another inductor created in the ground layer of the microstrip.

In this paper, a compact three-poles planar reconfigurable filter is designed using the CST tool to cover the frequency band of 3.4 to 3.8 GHz, suitable for 5G wireless communication applications. By adjusting the DC biasing voltage across to the varactor diodes, both the resonant frequency and the bandwidth of this filter are adjusted with a wide tuning range of about 400 MHz (3.4–3.8 GHz). Very good insertion loss of 1 dB has been achieved. Also, it is significant that this design can be easily developed and integrated with antenna design [40], to create the so-called “filtenna” [41- 46]. The filter design and its performance are presented and discussed in the next coming sections.”

2 Reconfigurable planar BPF design

The geometry of the proposed design is shown in Fig. 1. Three-ring resonators fed by two ports 50 Ω input impedance are used for reducing the physical size without the need for vias. The filter is designed with a transmission line feed and Rogers RO3010 substrate is used, with h = 1.27 mm, εr = 10.2 and loss tangent = 0.0022. The frequency 3.6 GHz is chosen as the resonance frequency because this frequency is suitable for 5G. Frequency reconfigurability is important for these designs to get tunability for multi-band systems and to cover the required variations. Using varactors is a famous technique for reconfigurable filters. Nevertheless, the position of the varactor effects the performance of the filter. The filter in this paper is designed with varactor diode and the biasing circuit necessary to tune both the resonant frequency and bandwidth characteristics. Two Inductors (L1=L2=10 nH) are used as radio frequency (RF) chokes to limit and reduce the leakage of the RF signal into the biasing circuit and powering wires by acting as an open circuit to the RF signal at the two ends of the switches. The optimized dimensions are achieved by using the built-in optimizer embedded with the CST software. The CST time domain solver has been used with 10 lines per wavelength as mesh density control properties. The dimensions of this filter are optimized to ensure good matching at the tuning range. The configuration of this filter and its optimized dimensions are shown in Fig. 1 and Table I, respectively.

The biasing circuit of the proposed tunable filter with the SPICE representation for the varactor is modeled as illustrated in Fig. 2. Practical switches (SMV1234) manufactured by incorporation of Skyworks Solutions with a size 1.5 x 0.7 mm2 can be used as a varactor switch.



(a)

(b)

Fig. 1. The geometry of the designed tunable BPF: (a) 2D geometry (b) 3D structure.

TABLE I. THE OPTIMIZED DIMENSIONS OF THE ANTENNA (UNITS IN MM)

L1	**L2**	**L3**	**L4**	**L5**	**L6**	**W1**	**W2**	**W3**
3.9	0.9	4.8	0.5	3.8	0.9	1.2	0.43	0.9

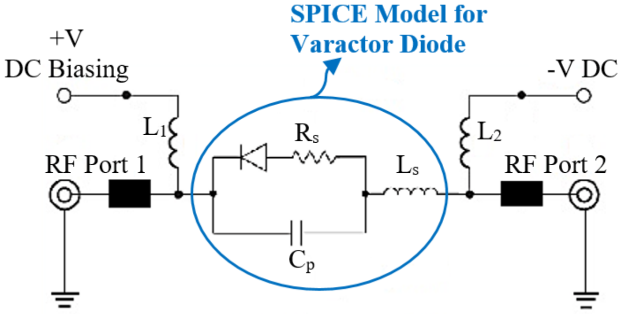


Fig. 2. Biasing circuit used for the proposed tunable filter.

3 Three-pole tunable filter performance

In this section, the performance of the tunable filter is studied in terms of return loss and insertion loss. The simulation results are generated using CST studio software. The simulation results for the return loss of proposed three-pole microstrip filter in Fig. 3 shows that by altering the biasing voltages of the varactor, the capacitance values (CT) will be changed accordingly with different values (2.6, 3.3, 4.8, 6 and 8.1 pF). It is shown that by increasing the capacitance of the varactor, the return loss will be reduced in tuned in the desired band necessary by the 5G application that is 3.4- 3.8 GHz. Good return loss is achieved during the overall band to be between -20 dB to -37 dB. In Fig. 4, the simulated values for the insertion loss have been achieved with different values corresponded to the values obtained in Fig. 3. Good insertion loss resulted during the tuning range of the resonant frequency with values around the -1 dB.

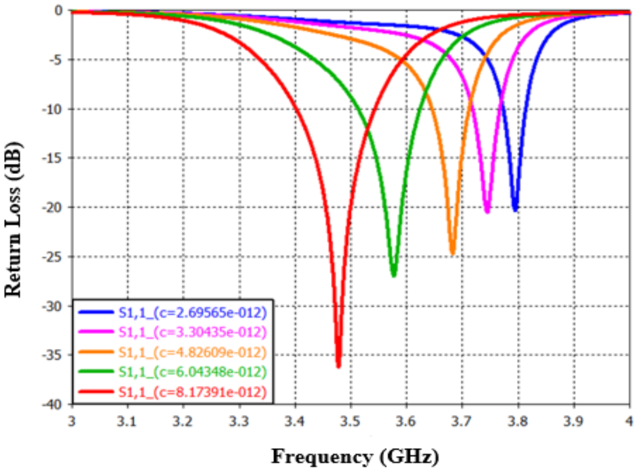


Fig. 3. Simulated results for S11 with different biasing voltages.

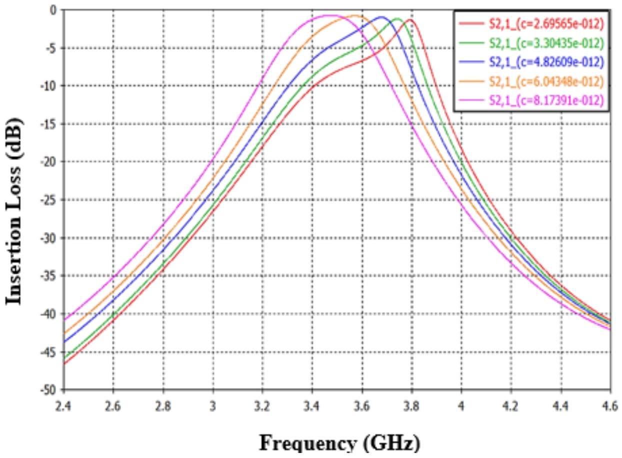


Fig. 4. Simulated results for S21 with different biasing voltages.

In addition to the tunability of the resonant frequency, the bandwidth is tuned with different appropriate values. It is clear from Fig. 3 and Fig. 4 that the bandwidth of 10 dB passband for the designed filter has been tuned in the range (50-130 MHz) according to the biasing of the varactor diode. The characteristics are obtained by using the CST tool, and the results of the parameters are been shown. Table II summaries the biasing circuit parameters achieved by the datasheet and the obtained performance for the reported microstrip filter.

TABLE II. SUMMARY OF THE ACHIEVED PERFORMANCE

Voltage (V)	**Varactor Capacitance (pF)**	**F_0 (GHz)**	**BW (MHz)**	**S11 (dB)**
-3.8	3.4	3.9	50	-22
-32.8	3	3.8	70	-24
-1.9	4	3.7	80	-27
-0.89	5	3.58	105	-29
-0.5	7	3.48	130	-37

4 Conclusion

A proposed compact design for a 5G reconfigurable-microstrip bandpass filter is presented in this paper with third-order and Butterworth filter properties. The filter is reconfigurable for both the resonant frequency and bandwidth to cover 3.4-3.8 GHz under the control of varactor diode switch. The proposed design exhibits 50-130 MHz bandwidth with return loss between -20 dB to -37 dB and insertion loss around the -1 dB. Only one varactor diode is used for tuning the filter. The bandpass tunable filter covers the 5G frequency spectrum for possible use in stationary terminals of different wireless communications and it is suitable for cognitive radio systems as well.

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