Abstract—This paper proposes a compact three-pole planar tunable bandpass filter (BPF) covering the sub-6 GHz spectrum for 5G wireless communications. The microstrip BPF utilizes three open-loop ring resonators with 50 Ω transmission line impedances for input/output terminals. The coupling coefficients between the adjacent resonators and the external quality factors are controlled to resonate the designed filter at 3.5 GHz with third-order bandpass Butterworth characteristics. The varactor diode and biasing circuit are modelled to tune the resonant frequency in the desirable band. The filter is implemented and measured on a Rogers RO3010 substrate with a relative dielectric constant of 10.2 and a compact size of 17×5×1.27 mm³. A planar microwave tunable BPF, to cover the frequency band of 3.4 to 3.8 GHz for 5G applications. It is simulated and measured using computer simulation technology (CST) tool. Good agreement is achieved between the simulated and measured results.

Index Terms—microstrip filter, bandpass, tunable, 5G, varactor, CST.

I. INTRODUCTION

Radio frequency noise is a serious issue in recent applications of wireless channels such as in green communications and wideband radar systems [1-6]. Planar bandpass BPFs are generally used to suppress unwanted noise signals in many wireless systems [7], mainly in radio frequency (RF) and microwave (MW) communications because of their efficient role to reject the spurious frequencies. Currently, next-generation technologies are being suggested for use in low-band (700 MHz), mid-band (3.6 GHz) and millimetre wave band (26 GHz) [8]. BPF is used in different 5G applications for rejecting noise frequencies [9,10]. A BPF consists of a number of poles, and the designs of the resonators and the number of elements define the filter properties. Most planar filter miniaturization techniques try to minimize and optimize these parameters [11-18]. Many approaches and structures have been presented such as Stepped-impedance resonators (SIR), combline, ring resonators, parallel-coupled lines, and stub impedance resonators [19-24].

A planar microwave tunable bandpass filter using a varactor diode is investigated for controlling a constant bandwidth in [19]. Tuning is achieved by controlling the resonant frequencies for both the odd and even modes as there is no coupling between these modes. In [20], a planar tunable filter uses two varactor diodes to adjust two transmission zeros (TZs). The resonant frequency and the bandwidth are adjusted with a wide tuning range of about 590 MHz (1.5 to 2.1 GHz) by controlling the DC biasing voltage across the varactor diodes. In [21], a compact reconfigurable microstrip filter with constant characteristic is presented. By controlling the DC biasing voltage of four varactor diodes, the filter is reconfigurable from 1.8 to 1.9 GHz with a 5% fractional bandwidth.

Recently, many designs of reconfigurable microstrip filters have been proposed and investigated. Chen et al. [23] described a second-order filter with compact size and constant bandwidth. Two varactor diodes tune the resonant frequency between the higher and lower modes of operation with a range of 1.2 to 1.9 GHz and constant bandwidth of 39 MHz. Its properties of small size (0.06 λg × 0.27 λg), continuous reconfigurability, simple design, and wide-rangin frequency make the filter suitable for current wireless communications. Ebrahimi et al. [24] propose a notch tunable band-stop filter by using two varactor diodes. The second-order filter illustrates a continuous tuning range of the resonant frequency of 0.7 to 1 GHz with a compact structure of size 0.15λg ×0.17λg. Unlike the previous structures, the inductive coupling is obtained using an inductor in the ground layer of the microstrip.

This article presents a compact third-order microstrip open-loop ring resonator tunable BPF, to cover the frequency band of 3.4 to 3.8 GHz for 5G applications. It is simulated using CST software. The filter is fabricated on a Rogers RO3010 substrate with a relative dielectric constant of 10.2 and a compact size of 17×5×1.27 mm3. Controlling the DC biasing voltage across the varactor diode gives a wide tuning range of about 3.4 to 3.8 GHz for the resonant frequency,
with 50-130 MHz tunable bandwidth. Significantly, this filter can be easily developed and integrated with antenna structures [25], to produce the so-called “filtenna” [26]. The tunable BPF, with simulated and measured results, is presented in the following sections.

II. OPEN-LOOP TRISECTION BPF DESIGN AND PERFORMANCE

The geometry of the proposed 3-pole open-loop BPF is shown in Figure 1. The filter consists of three open-loop ring resonators and is fed by two ports of 50 Ω input impedance to minimize the physical size and eliminate the need for vias. The filter has a transmission line feed and uses a Rogers RO3010 substrate, with h = 1.27 mm, εr = 10.2 and loss tangent = 0.0022. The resonant frequency 3.5 GHz is chosen as suitable for 5G applications. The configuration of the filter and its dimensions are shown in Fig. 1 and Table I, respectively.

The frequency performance is shown in Fig. 2. At the resonant 3.45 GHz frequency, the filter has a good return loss 20dB for the targeted 5G spectrum and covers the 3.4 to 3.5 GHz band with fractional bandwidth 3%. At resonance, the insertion loss has a minimum value 0.9dB as shown in Figure 2. Wide stop bands of 3 GHz and 2.5 GHz are achieved for the lower edge and the upper edge of the passband respectively, each with insertion losses more than 10 dB. The selectivity of the passband bandwidth could be improved in a for higher order filter by increasing the number of resonators. Fig. 3 elaborates the current distribution of the filter at the resonant frequency of 3.45Hz, obtained using CST software: the electric field is mainly distributed in the first and third open-loop resonators, with maximum current density 58 A/m in the first resonator element. The next section discusses the filter’s tunability characteristics.

III. THREE-POLE TUNABLE FILTER PERFORMANCE

Frequency reconfigurability or tunability is important for multi-band systems to cover the required variations. The use of varactors is a well-known technique for reconfigurable filters. Fig. 4 shows the geometry of such a proposed filter, including the biasing circuit required to tune the varactor diode and two RF choke inductors to prevent the RF signal passing through the biasing circuit. The biasing circuit controls both the resonant frequency and bandwidth characteristics. This filter uses the SMV1234 Skyworks Solutions varactor diode, size 1.5 x 0.7 mm². Increasing the reverse voltage widens the depletion region of the varactor, decreasing its capacitance, and vice versa: see Fig. 5 (a). In addition, two inductors (L1 = L2 = 10 nH) are used as radio frequency (RF) chokes to limit and reduce RF leakage into the biasing circuit and power leads; they act as open circuits to the RF signal at the ends of the switches. The optimized parameters are obtained using CST software. The CST time domain solver uses 10 lines per wavelength as mesh density control parameter, and the filter dimensions are optimized for good matching over the tuning range. The filter’s biasing circuit, with the SPICE model for the varactor, is modelled as shown in Fig. 5 (b).
IV. THREE-POLE TUNABLE FILTER PERFORMANCE

In this section, the return loss and insertion loss of the filter are studied. The simulation results for the return loss shown in Fig. 6 (a), indicate that different reverse bias voltages of the varactor between 0 V and 4 V, give capacitance values of 2.7, 3.3, 4.8, 6 and 8 pF, altering the return losses in the 3.4 to 3.8 GHz range, between -17 dB and -30 dB. Fig. 6 (b) shows the simulated insertion losses for the values corresponding to those of Fig. 6 (a). Good insertion losses are obtained over the tuning range, of around 1 dB at resonance. In addition to the tunability of the resonant frequency, the bandwidth is also altered. In short, Figure 7 shows that the 10 dB passband bandwidth tunable over the range 40 to 140 MHz. Fig. 7 shows the fabricated prototype. Fig. 8 shows the measured return loss and the insertion loss of the filter. The CST simulation results and the measurements from the vector network analyser (HP 8510C) show fairly good agreement. Fig. 9 shows the frequency response of the group delay for all the states of the varactor diode.
filter with other recent similar designs. The filter proposed here has a relatively good performance in respect of performance, size, number of switches and design complexity.

V. CONCLUSION

A design for a compact 5G reconfigurable-microstrip bandpass filter with third-order and Butterworth properties is presented in this paper. The filter is reconfigurable in both resonant frequency and bandwidth, covering 3.4 to 3.8 GHz under the control of a single varactor diode switch. The bandwidth is adjustable between 40 and 140 MHz with return losses between 17 to 30 dB and insertion loss around 1 dB. The filter covers the sub-6 GHz 5G spectrum for possible application in stationary terminals of cognitive radio systems and other applications in future wireless communications. Good agreement between measurement and simulation results proves the reliability of the proposed design.

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REFERENCES


