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Spiral Microstrip Bandpass Filters

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ABSTRACT

Microstrip bandpass filters based on spiral resonators are designed at 700MHz for 5G applications. In order to achieve size reduction, spiral resonators are used. The proposed filters are of third and fifth orders. The filters are printed on FR4 substrate with thickness of 1.6mm and dielectric constant of 4.5. The filters are simulated using CST electromagnetic simulator. The simulated results show that the presented filters exhibit good return losses, low insertion losses within the passband. Furthermore, a good selectivity is obtained. The simulated reflection coefficients are -15 dB and -12 dB for the 3rd and 5th order filters respectively. The fifth order bandpass filter provides higher selectivity but higher insertion loss as expected.

Keywords: *Microstrip Filters, Bandpass Filters, Spiral Resonators, Small Filters*

1. Introduction

Modern Communication systems require bandpass filters (BPFs) with low insertion loss, high selectivity, and small size. BPFs are typically used to reject or attenuate undesirable interfering signals. Current technologies are being used in low-band 700 MHz, mid-band 3.6GHz, and millimetre wave band at 26GHz [1]. Many research works have been dedicated for the miniaturizing microstrip bandpass filters [2-4].

Many topologies have been suggested including combline, ring resonators, parallel-coupled lines, stub impedance resonators, and stepped-impedance resonators [5-7].

In this paper two microstrip bandpass filters based on spiral resonators are presented. The microstrip filters are designed to pass signals at 5G 700MHz frequency band. The objective of this design is to obtain small and compact size filters at such low frequency. To do so, spiral square resonators are used. Two filters of third and fifth order are proposed in this paper. The spiral resonator consists of multiple folded turns in order to achieve a small size.

2. Filter Structure and Design

The proposed spiral BPFs are shown in Fig.1. Each filter consists of square spiral resonators and tapped feed lines. Each resonator is approximately half wavelength long at the midband frequency of 700 MHz. The resonator is 30x25 mm with a line width of 1mm.

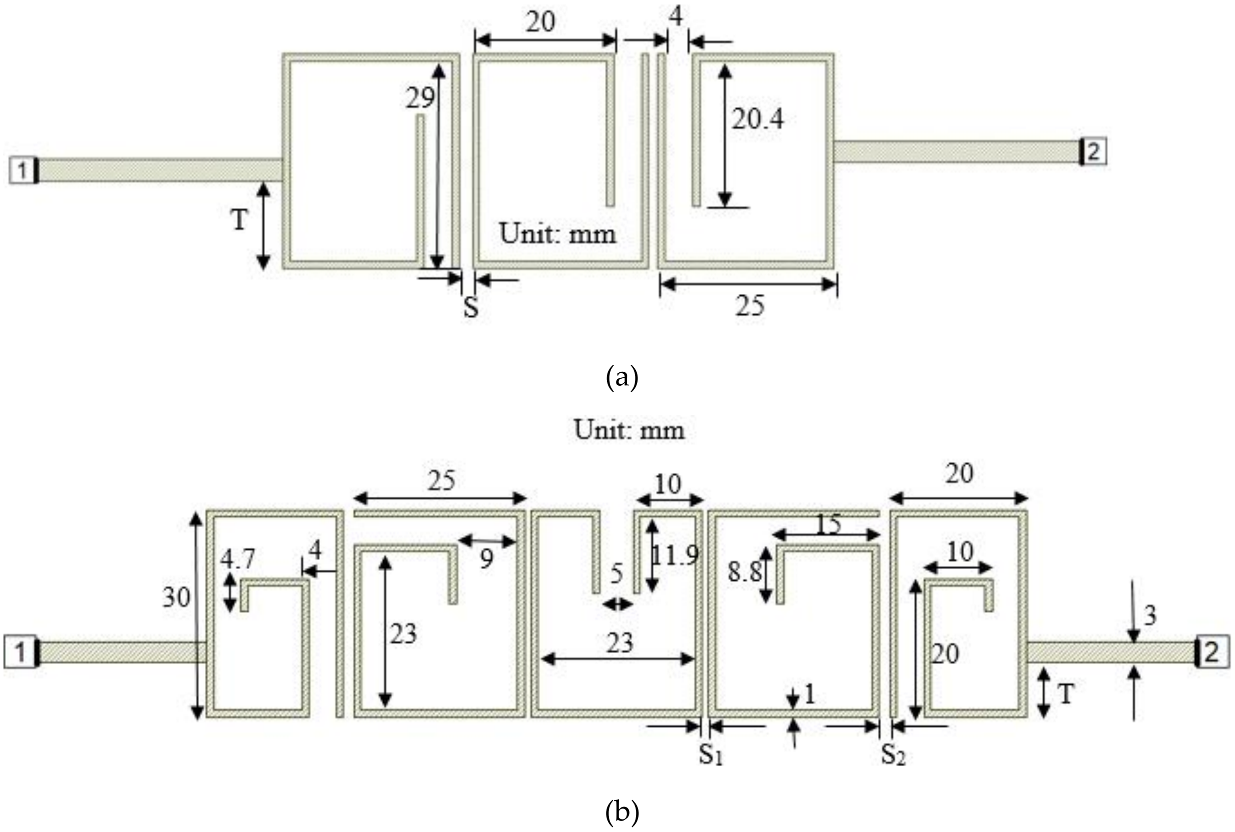


Figure 1: The spiral microstrip BPFs: (a) Third-order BPF; (b) Fifth-order BPF.

In (a): T=12.2mm, S=1.6mm. In (b): T= 7.9mm, S_1 = 1.6mm, S_2 = 1.8mm.

The filters are implemented using RF4 dielectric substrate with a thickness of 1.6mm, dielectric constant of 4.5, and loss tangent of 0.008. The feed line is designed to have characteristic impedance of 50Ω and thus its width is 1.6mm. The filter is designed to have Chebyshev equal ripple response with pass-band ripple of 0.0432 dB.

A spiral resonator is used in the design of the microstrip 5G 700MHz bandpass filter. Each resonator is approximately half-wavelength long at the centre frequency of the bandpass filter. Thus, the physical length of the resonator is approximately given by Eq. (1).

$$L_r = \frac{\lambda}{2} = \frac{C}{2f\sqrt{\epsilon_r}} = \frac{3 * 10^8}{2 * 700 * 10^6 * \sqrt{4.5}} = 101mm \tag{1}$$

The width of the resonators ranges between 1-2mm. In the 5G 700MHz filter design, the width is chosen to be 1mm and the spacing of the arms is 3 mm to minimize the lines coupling within the same resonator. The filters are designed to have fractional bandwidth of 0.04.

The gaps between the resonators and the physical dimensions of the filter are obtained using the parameter extraction method, which is based on the electromagnetic simulations as described in [8].

For the third-order BPF, the element values of the lowpass prototype with 0.0432 dB equal-ripple response are used. The element values are: g_0 = 1.0, g_1=0.8516, g_2 = 1.1032, g_3 = 0.8516. The external quality factor and the coupling coefficients can be defined through the equations [8]:

$$Q_{e1} = \frac{g_0 g_1}{FBW} = Q_{e3} \tag{2}$$

$$M_{i,i+1} = \frac{FBW}{\sqrt{g_i * g_{i+1}}} \tag{3}$$

The design parameters have been calculated and found to be $Q_{e1} = Q_{e3} = 15$ and $M_{12} = M_{23} = 0.0433$.

The parameter extraction method is used to find the filter dimensions. The arrangement which is shown in Figure 2 is used for extracting the external quality factor Q_e.. The position T of the tapped feed line is changed and Q_e is calculated for each corresponding value of T as described in [9]. The design curve for the external quality factor Q_e against the tapping position T is obtained and shown in Figure 2. It can be seen that as t increases, Q_e increases and the coupling decreases.

The inter-resonator coupling coefficient is extracted from the arrangement shown in Figure 3. The gap between the resonators is increased from 0.5mm to 2.5mm and the coupling coefficient is computed as described in [9]. As the gap g increases, the coupling decreases and $M_{i,i+1}$ decreases as shown in Figure 3.

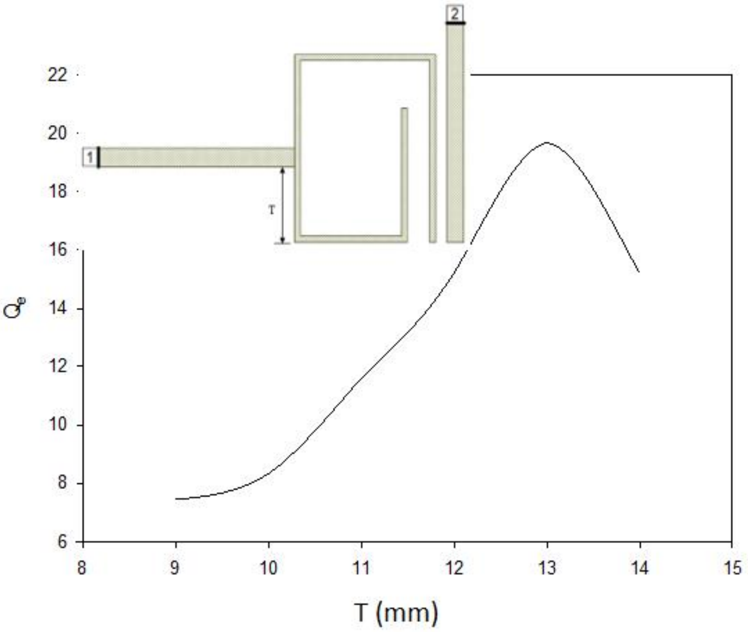


Figure 2: Extracting the external quality factor Q_e for the 3rd order BPF.

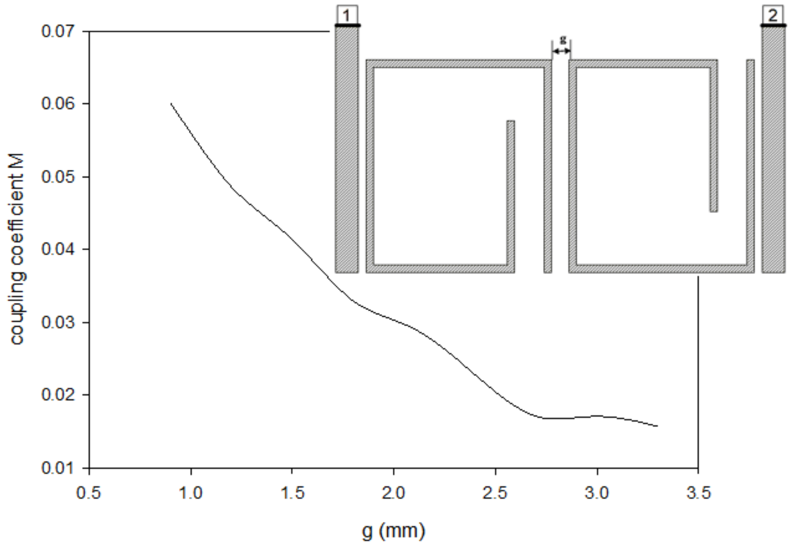


Figure 3: Extracting the coupling coefficient $M_{i,i+1}$ for the 3rd order BPF.

From the design curves obtained above, the physical dimensions of the filter are determined, which are $T = 12.2$ mm, S = 1.6 mm.

For the fifth-order BPF, the element values of the lowpass prototype with 0.0432 dB equal-ripple response are used. The element values are: $g_0 = g_6 = 1.0$, $g_1 = g_5 = 0.9714$, $g_2 = g_4 = 1.3721$, $g_3 = 1.8014$. The design parameters have been calculated and found to be $Q_{e1} = Q_{e3} = 19.4$ and $M_{12} = M_{45} = 0.043$, and $M_{23} = M_{34} = 0.0318$. Figure 4 shows the simulation setup to obtain Q_e for the 5th order BPF. Figure 5 shows the design curves for the coupling coefficients.

From the design curves obtained below, the physical dimensions of the filter are determined, which are $T = 7.9$ mm, $S_2 = 1.6$ mm, and $S_1 = 1.8$ mm.

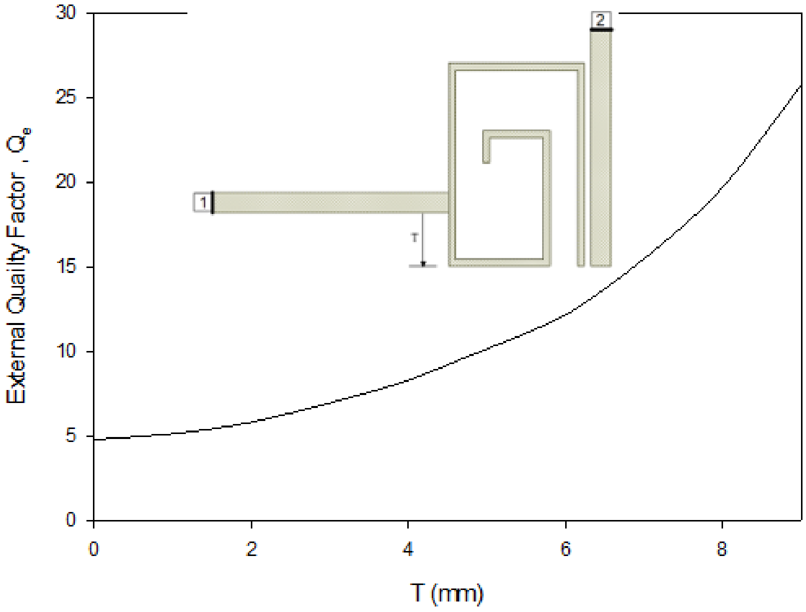
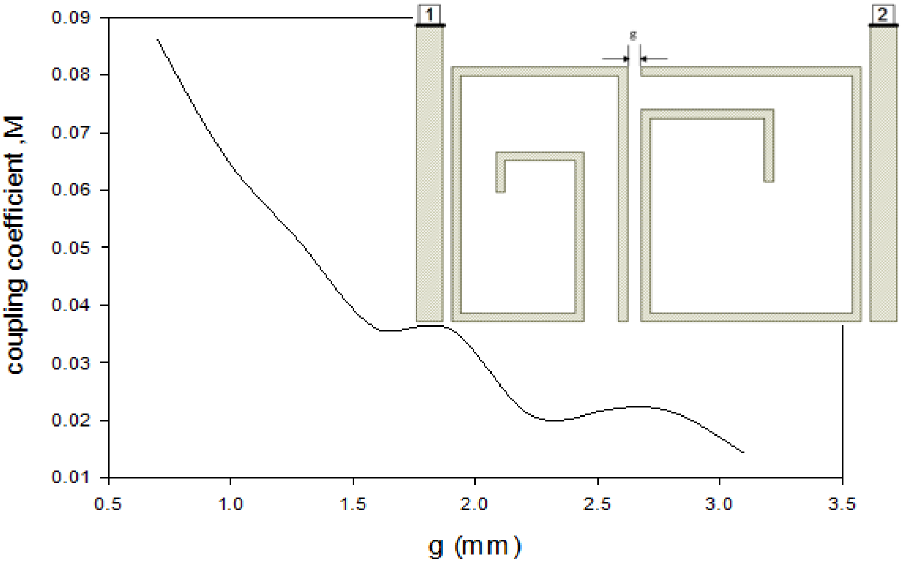
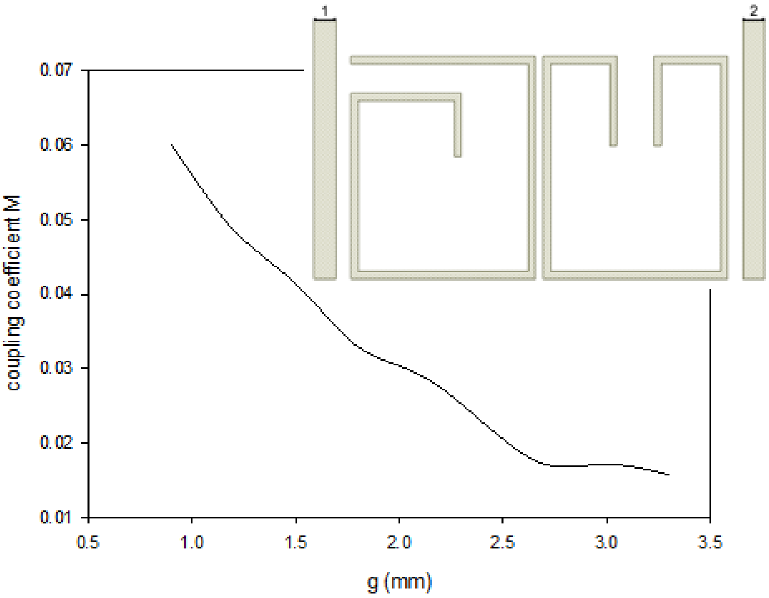


Figure 4: Extracting the external quality factor Q_e for the 5th order BPF.



(a)



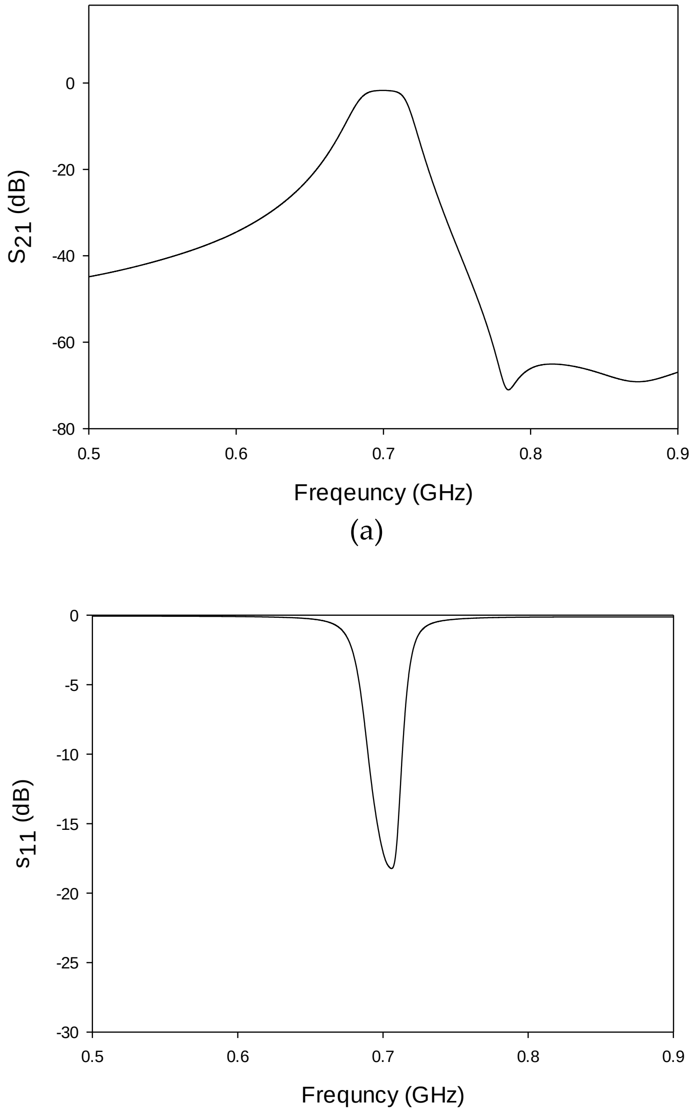
(b)

Figure 5: Extracting the coupling coefficient for the 5th order BPF.

(a) M_{12}/M_{45} (b) M_{23}/M_{34}

3. Simulation Results

The proposed bandpass filters have been simulated using CST®. Finite-different time-domain (FDTD) method has been used. Figure 6 depicts the simulated performance of the 3rd order BPF. The simulated midband frequency is at 700MHz with simulated return loss better than -15 dB within the passband. The insertion loss of this filter is shown in Figure 6a. The simulated insertion loss is better than -1.6 dB. This loss is attributed to the dielectric losses of the substrate which has a loss tangent of 0.008.

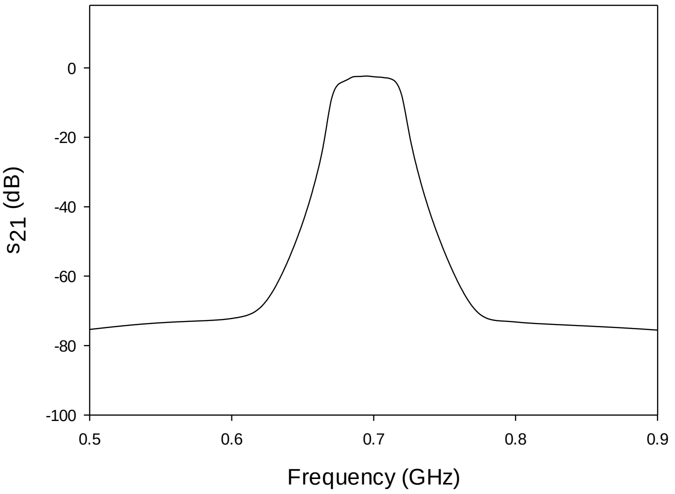


(a)

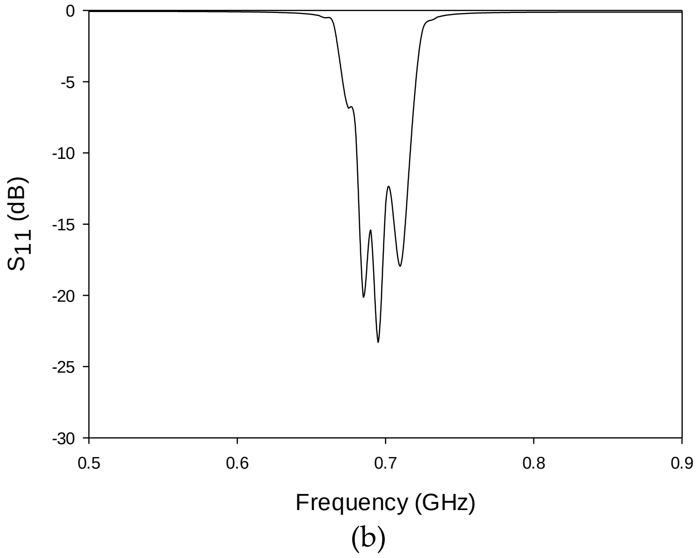
(b)

Figure 6: The EM simulated performance of the filter: (a) S_{21} (b) S_{11}

Figure 7 depicts the simulated performance of the 5th order BPF. The insertion loss of this filter is better than -3 dB as shown in Figure 6a. The simulated midband frequency is at 700MHz with simulated return loss better than -12 dB within the passband.



(a)



(b)

Figure 7: The final EM simulated performance of the 5th order BPF (a) S_{21} (b) S_{11}

4. Conclusion

Microstrip BPFs are proposed for mobile communication systems. The filters are designed for the 5G 700MHz frequency band. They consist of spiral resonators and a tapped fed lines. Two direct-coupled filters of third and fifth orders are presented. The filters are designed and simulated using CST based on the parameter extraction method. The proposed filters provide good performances in terms of return loss and insertion loss.

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