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Tunable Microstrip Bandpass Filter with Wide Tuning Range

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Abstract

A tunable microstrip bandpass filter is presented. The filter is of a third order and based on general Chebyshev filtering response. It consists of three short-circuited microstrip line resonators whose length is λ/8 at the centre frequency of 1.5 GHz. The frequency tuning is achieved by connecting variable capacitors to the end of the resonators. The tuning range extends from 1.1 to 2.5 GHz. The insertion loss is better than -1 dB within the operating range. The proposed bandpass filter is designed and simulated using CST® software package. The simulated results demonstrate a good frequency selectivity, wide tuning range and low insertion losses.

Keywords: *Bandpass, Tuning Range, length, frequency, Wireless.*

1. Introduction

Bandpass filter (BPF) is an important element of modern RF/Microwave systems. Modern wireless communication systems are required to operate at multiple frequencies, thus the BPF must be able to tune its centre frequency (passband) over a wide frequency range [1]. Frequency reconfigurability allows in RF architectures is promoted in order to reuse the same hardware and dynamically reconfigure its operation mode according to the user's demand. Hence, reconfigurable bandpass filters will be desired to accommodate various bandwidth requirements of different standards, reducing costs, and adapting to regulatory changes [2]. Furthermore, much sharper filter responses result in higher isolation between closely spaced frequency spectrums, i.e., more revenue due to more efficient use of frequencies. These highly selective and tunable filters with low insertion losses are synthesized with previously developed techniques [3].

The common way to realize reconfigurable filter is by cascading multiple resonators and the centre frequency tunability is achieved by using active tuning elements such as semi-conductor PIN diodes [4-5], RF MEMS devices [6-7], or varactor diodes [8-9] to adjust the electrical lengths of the resonators.

2. Design and Analysis

The proposed BPF is shown in Figure 1. It consists of three coupled microstrip line resonators. Each resonator is approximately λ/8 long at the centre frequency and short circuited at both ends. A variable capacitor is connected to one end of each resonator to adjust its electrical length. The two short-circuited lines at the input and output are not resonators, but simply part of impedance-transforming sections that allows input and output couplings [2]. The filter is implemented on FR4 substrate with thickness h =0.8mm, a dielectric constant of 4.3, and loss tangent of 0.010. The filter is designed based on equal-ripple filtering (Chebyshev) response with 0.0432 dB passband ripple. The lowpass prototype elements for the lowpass prototype are found to be $g_0 = g_4 = 1.0$, $g_1 = g_3 = 0.8516$, g_2=1.1032 [2].

The centre frequency is chosen to be f_0 = 1.5 GHz and the fractional bandwidth is FBW = 0.08. For a wide tuning range, the electrical length of each resonator is chosen to be $\theta_0 = 45°$. Thus, the resonators are λ/8 long at the centre frequency. Y_a is the characteristic admittance of the resonator and is chosen to be 70 Ω. Therefore, the width of the resonator is 0.8mm. The value of the loading capacitance at f_0 is found from [2]:

$$C_L = \frac{Y_a \cot\theta_0}{2\pi f_0} = \frac{\left(\frac{1}{70}\right) * \cot 45°}{2 * 3.14 * 1.5 * 10^9} = 1.52\, pF$$

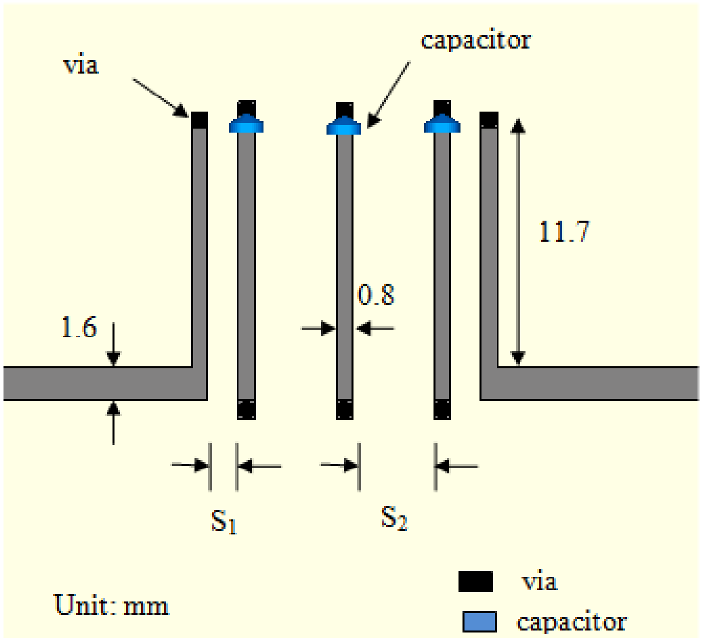
The external quality factors and coupling coefficients can be determined from

$$Q_e = \frac{g_0 g_1}{FBW} = \frac{1.0 * 0.8516}{0.08} = 10.65 \tag{1}$$

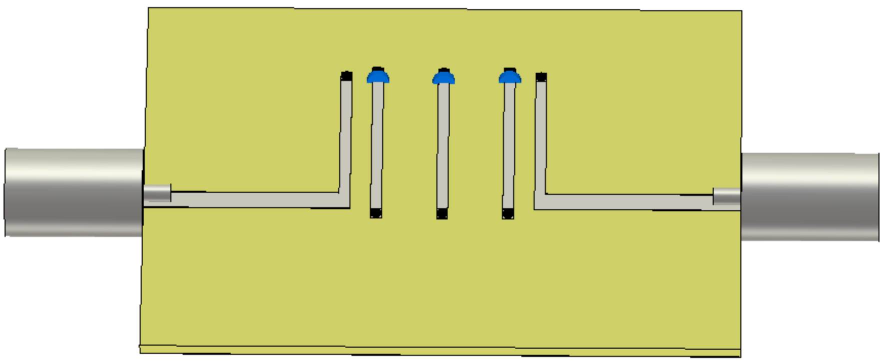
$$M_{12} = M_{23} = \frac{FBW}{\sqrt{g_1 g_2}} = \frac{0.08}{\sqrt{0.8516 * 1.1032}} = 0.0825 \tag{2}$$

Table 1: The design specification for the proposed tunable BPF

Centre Frequency	1.5 GHz
Fractional Bandwidth	8%
Order	3
Filtering Response	Chebyshev with 0.04321 dB passband ripple



(a)



(b)

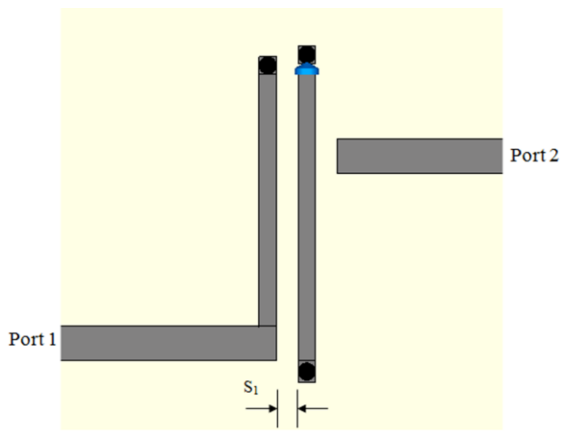
Figure 1: The proposed tunable BPF

(a) 2-D front view; (b) 3-D view

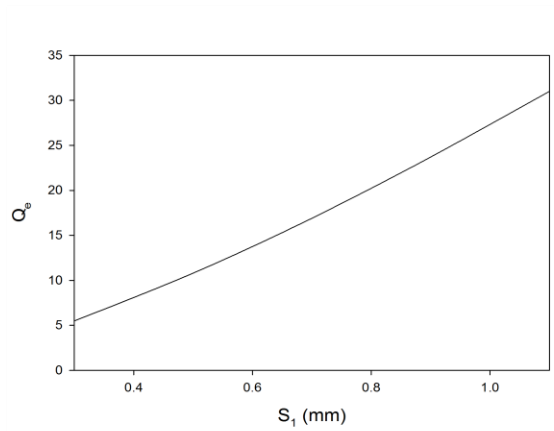
The physical dimensions of the filter are found using the parameter extraction technique described in [2]. Figure 2a shows an arrangement for extracting the Q_e. In this arrangement, port 2 is weakly coupled to the resonator. Q_e is extracted from the simulated transmission coefficient as:

$$Q_e = \frac{f_0}{\Delta f} \qquad (3)$$

where f_0 is the centre frequency and Δf is the 3-dB bandwidth. The spacing S_1 is varied and Q_e is calculated from (1). A design curve for Q_e is obtained as shown in Figure 2b.



(a)



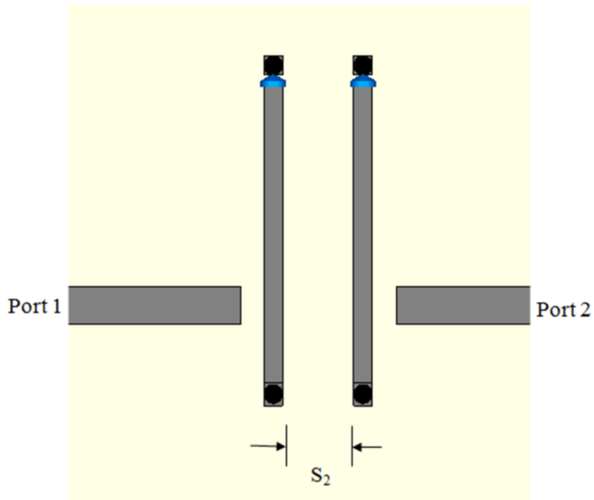
(b)

Figure 2: (a) an arrangement for extracting Q_e

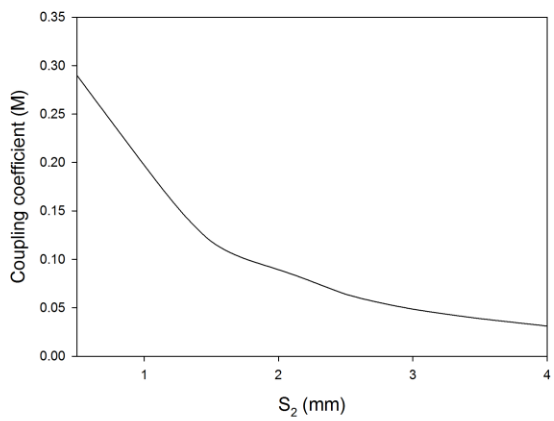
(b) the design curve Q_e vs. S_1

Figure 3 shows an arrangement for extracting the inter-resonator coupling coefficients (M_{12}, M_{23}). The coupling coefficient is extracted from the simulated transmission coefficient (S_{21}) as described in [2]. Two resonant peaks (f_1 and f_2) can be observed in the S_{21} response and M can be calculated from (4)

$$M_{12} = M_{23} = \frac{f_2^2 - f_1^2}{f_2^2 + f_1^2} \qquad (4)$$



(a)



(b)

Figure 3: (a) an arrangement for extracting M_{12}, M_{23}, (b) Design curve for M_{12}, M_{23}

3. Simulation Results and Analysis

The simulated electromagnetic performance of the BPF is shown in Figure 4. The filter has been simulated using both Finite-Different Time-Domain (FDTD) and Finite-Element Method (FEM) techniques. The simulated FDTD result shows that the centre frequency is at 1.5 GHz and the insertion loss is about -0.5 dB. The 3-dB bandwidth is about 100 MHz. The magnitude of the return loss is better than -20 dB within the passband. A small shift in the centre frequency is observed in the FEM simulated result towards 1.51 GHz. The FEM simulated insertion loss is about -1.3 dB. The results are in good agreement. Figure 5 shows the variation of the return and insertion losses with the loading capacitance C_L. It can be seen that the centre frequency decreases from 2.5 to 1.1 GHz as the loading capacitor C_L increases from 0.2 to 3.0 pF.

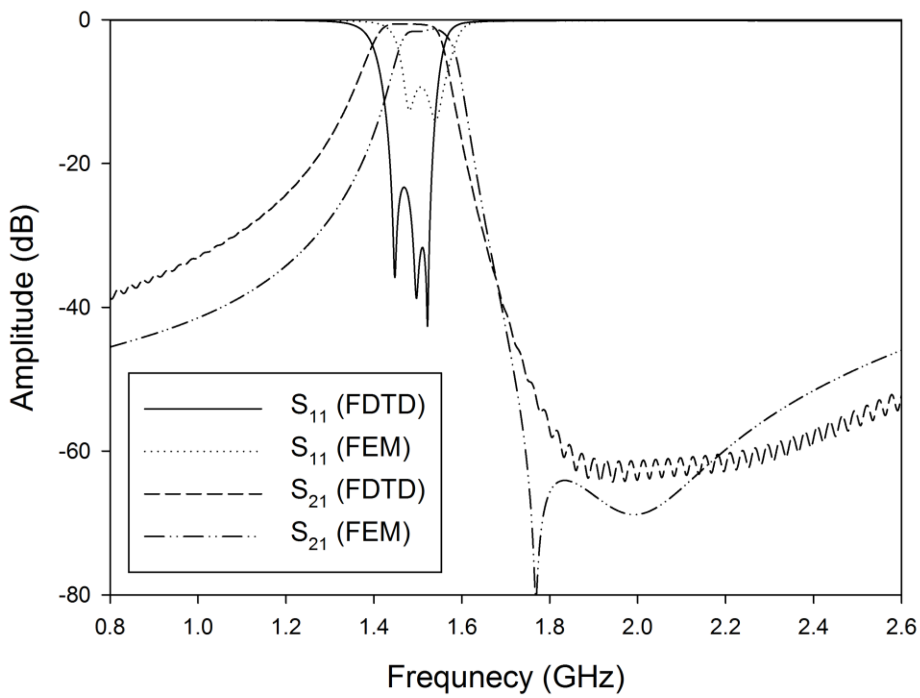
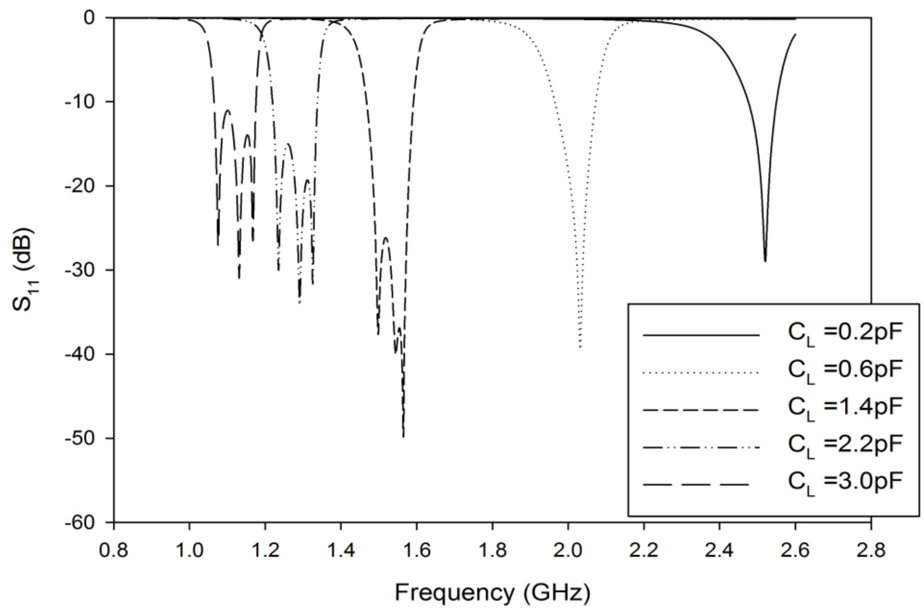


Figure 4: The simulated filter response of the filter with C_L =1.52 pF.

(g_1 = 0.5mm and g_2 = 2.2mm)



(a)

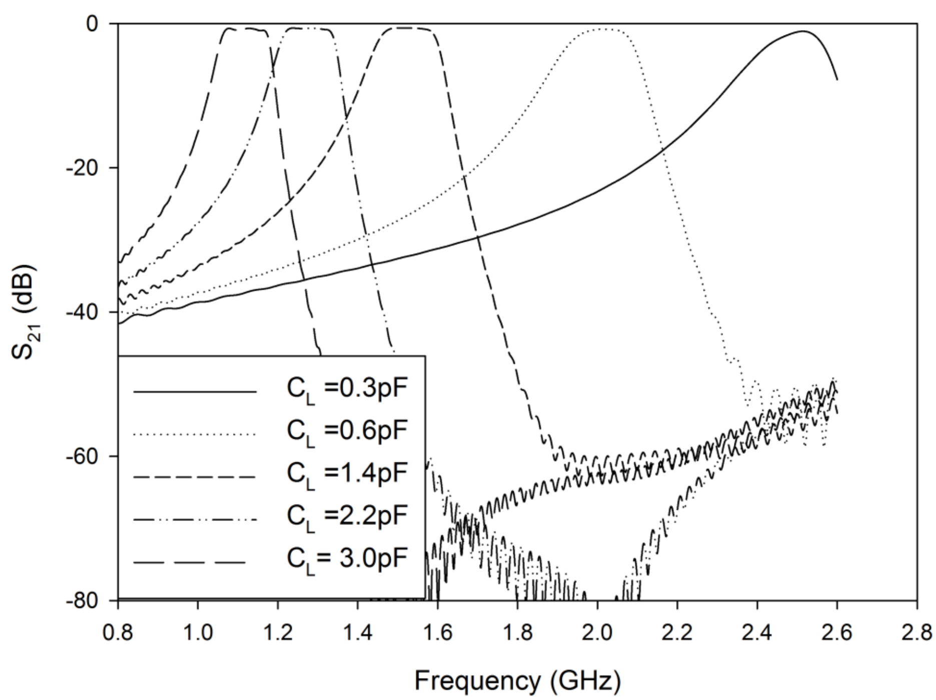


Figure 5: (a) S_{11} vs. C_L; (b) S_{21} vs. C_L

4. Conclusion

A tunable microstrip bandpass filter with wide tuning range is presented. The filter is of a third order and consists of λ/8 long coupled resonators. The resonators are short-circuited at one end and connected to lumped capacitors at the other end. The frequency tuning is achieved by varying the capacitance. The tuning range extends from 1.1 to 2.5 GHz with insertion loss better than -0.5 dB.

References

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