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Design of Novel Cross-Coupled Trisection Bandpass Filters with Open-Loop Resonators

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Abstract— In this paper the method of designing and simulating the cross-coupled trisection bandpass filter using open-loop resonators centered at 1.025 GHz is presented. The filter has a cross coupling that produces a single attenuation pole at finite frequency used to shape the bandpass response. These new resonator is applied to design bandpass filter with pseudo-elliptic response. We have performed an electromagnetic simulation under CST MWS environment. The result is an attenuation pole of finite frequency on the high side of the passband, therefore exhibiting asymmetric frequency response. The simulated trisection filter with a centre frequency exhibits an insertion loss of 0.6 dB and a return loss of −20 dB and 3−dB bandwidth of [972−1078] MHz. The rejection is larger than 30 dB at 1.09 GHz.

Index Terms—Bandpass filters, square ring, trisection microstrip line, open loop resonator, asymmetrical characteristics, one side selectivity, frequency response.

1 Introduction

WITH the fast development of wireless communication systems, there is an increasingly demand for high quality components at microwave frequencies. Increasing demands for bandpass filters (BPFs) in order to get better performance for wireless communications systems with regards of minimum insertion loss in the passband, high return loss for the stopband, high selectivity at the bandpass edges and reduced size, inspire us to look forward than Chevyshev filters. Planar filters structures that are fabricated using print circuit technologies are preferred because of their smaller size, lower cost and lighter weight [1].

A type of microstrip resonator exhaustively investigated is the well-known square open-loop resonator [1]. Several authors have proposed modifications in this geometry to achieve miniaturization [1-2]. The hairpin square open-loop resonator is one of the microstrip geometries based on the square open-loop that presents a good size reduction.

In this work, we propose a compact size, low insertion loss and hairpin microstrip and we present a narrow-band trisection bandpass filter operating in the WLAN band with relative bandwidth of 10.38% and asymmetrical characteristic.

2 Bandpass Filter Strucrure

A cross-coupled structure in filters is used to achieve high selectivity response [3]. Transmission zeros created by the cross coupling between nonadjacent resonators improve the rejection bands of the filters [4]. The folded arms allows getting a compact structure, filters with open loop rings behave very similar to filters by Hairpin resonators, it means that the coupling effects between the two rings barely affect the locations of the two transmission zeros.

The configuration of the proposed microstrip cross-coupled trisection bandpass filters is shown in Fig.1. Due to the proximity of resonators 1 and 3, a cross-coupling between these resonators exists, which will create a transmission zero in the transmission function of the filter.

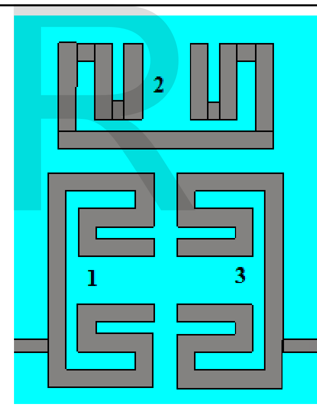

Fig. 1. Layout of the trisection bandpass filter.

In the case of a narrow band configuration, the equivalent circuit of trisection bandpass filter is given in Fig.2 [5]. It consists of three parallel resonators coupled with unity admittance inverters. The admittance inverter J_{13} represents the cross-coupling between resonators 1 and 3, J_{12} and J_{23} represent direct couplings between resonators 1 and 2, and, 2 and 3 respectively.

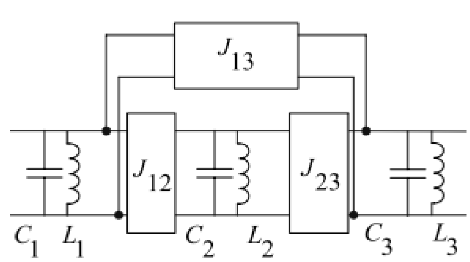

Fig. 2. Equivalent circuits of the filter Bandpass filter.

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3 Equivalent circuit and analysis

A narrowband three-pole trisection filter has the equivalent circuit shown in Fig. 3 [1]. The mutual inductance or coupling coefficient M_{ij} refers to the *i*th and *j*th resonator.

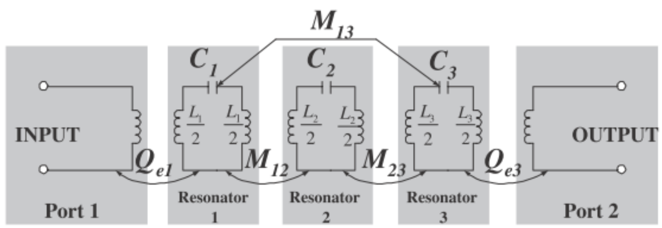

Fig. 3. Equivalent circuit of a three-pole trisection filter.

The cross coupling, M_{13} will determine the selectivity at a finite frequency. The external quality factors are denoted by Q_{e1} and Q_{e3} at the input and output ports. A trisection filter will have an attenuation pole at one side of the passband, and it requires the resonators to be asynchronously tuned to give an asymmetric filter frequency response. Thus, the resonating frequency for each resonator may be different and must be chosen to satisfy the filter requirements.

The angular resonant frequency of resonator *i* is given by [1]

$$\omega_{0i} = \frac{1}{\sqrt{L_i C_i}} = 2\pi f_{0i} \ \text{ for } \ i = 1, 2, 3 \tag{1}$$

Where L_i and C_i are the inductance and capacitance values of the equivalent circuit.

To keep the physical configuration of the filter symmetrical even though the frequency response is asymmetric, the following assumptions are made [1],

$$M_{12} = M_{23} \tag{2}$$

$$Q_{e1} = Q_{e3} \tag{3}$$

$$\omega_{01} = \omega_{03} \tag{4}$$

Figure 4 shows the low pass prototype filter transformed from the equivalent circuit in Fig. 3. It uses J inverters with [1],

$$J_{12} = J_{23} = 1 \tag{5}$$

The lowpass prototype of the proposed filter is shown in Fig. 4. Each resonator represents a frequency invariant immittance inverter and J_{ij} are the characteristic admittance of the inverter. In our case $J_{12}= J_{23} = 1$ for the inverters along the main path of the filter. The bypass inverter with a characteristic admittance J_{13} accounts for cross coupling between adjacent resonators. g_i and B_i (i = 1, 2, 3) denote the capacitance and the frequency invariant susceptance of the low pass prototype filter, respectively. g_0 and g_4 are the resistive terminations at the input and output ports.

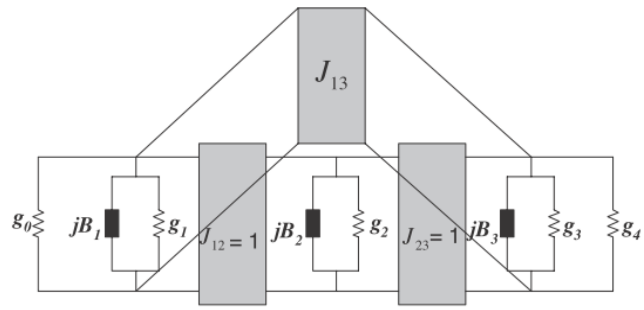

Fig. 4. Low pass prototype of the proposed filter.

$$g_0 = g_4 \tag{6}$$

$$g_1 = g_3 \tag{7}$$

$$B_1 = B_3 \tag{8}$$

The unknown low pass element values may be determined by a synthesis method [6]. Using the low pass to band pass frequency transformation, and some manipulation we can solve for L_i and C_i.

$$C_i = \frac{1}{\omega_0}\left(\frac{g_i}{FBW} + \frac{B_i}{2}\right) \tag{9}$$

$$L_i = \frac{1}{\omega_0}\left(\frac{g_i}{FBW} - \frac{B_i}{2}\right) \tag{10}$$

$$\omega_{0i} = \frac{1}{\sqrt{L_i C_i}} = \omega_0 \sqrt{1 - \frac{B_i}{g_i/FBW + B_i/2}} \tag{11}$$

Where ω_0 is angular frequency in center frequency, and ω_{0i} is angular resonance frequency of *i*th resonator, and FBW is the fractional bandwidth of band pass filter.

Finally, in order to derive the expressions for the external quality factors and coupling coefficients, we define a susceptance slope parameter of each shunt resonator in Fig. 3 as follows:

$$b_i = \omega_{0i} C_i = \frac{\omega_{0i}}{\omega_0}\left(\frac{g_i}{FBW} + \frac{B_i}{2}\right) \tag{12}$$

So the external quality factor, Q_{e1} and Q_{en}, and the coupling coefficient M_{ij} can be found by [1]:

$$Q_{e1} = \frac{b_i}{g_0} = \frac{\omega_{0i}}{g_0 \omega_0}\left(\frac{g_1}{FBW} + \frac{B_1}{2}\right) \tag{13}$$

$$Q_{en} = \frac{b_n}{g_{n+1}} = \frac{\omega_{0n}}{g_{n+1}\omega_0}\left(\frac{g_n}{FBW} + \frac{B_n}{2}\right) \tag{14}$$

$$M_{ij/i\neq j}=\frac{J_{ij}}{\sqrt{b_i b_j}} \tag{15}$$
$$=\frac{\omega_0}{\sqrt{\omega_{0i}\omega_{0j}}}\frac{FBW.J_{ij}}{\sqrt{\left(g_i+\frac{FBW.B_i}{2}\right)\left(g_j+\frac{FBW.B_j}{2}\right)}}$$

Where n is the degree of the filter or the number of the resonators.

3 Design and Implimentation of Bandpass Filter

For our demonstration, the filter is designed to meet the following specifications:

- Centre frequency = 1.0251 GHz,
- Bandwidth of passband = 106.4 MHz,
- Fractional bandwidth = 10.38% and,
- Return loss in the passband ≤ − 20 dB

Based on the centre frequency and required fractional bandwidth, the element values of the low pass prototype filter are founded: $g_1 = g_3 = 0.61$, $g_2 = 1.2$, $B_1 = B_3 = 0.2$, $B_2 = -0.615$, $J_{12} = J_{23} = 1.0$, $J_{13} = -0.27$.

When the element values are obtained, the design parameters for the trisection filter are calculated as follows:

- Resonant frequency for resonator 1 and 3: $f_{01} = f_{03} =$ 1.0613GHz,
- Resonant frequency for resonator 2: $f_{02} = 1.1062$GHz,
- External quality factor: $Q_{e1} = Q_{e3} = 1.1717$,
- The mutual coupling matrix of the filter is :

$$M=\begin{bmatrix}-0.0323 & 0.1153 & -0.0437\\ 0.1153 & 0.0506 & 0.1153\\ -0.0437 & 0.1153 & -0.0323\end{bmatrix}$$

In figure 5, we show the theoretical frequency response of the designed filter.

The trisection filter was designed to be fabricated using copper metallization on a substrate with a relative dielectric constant of 10.8, a thickness of 1.27 mm and a loss tangent of 0.002.

Its geometrical parameters are: W_{50} =1.08 mm (width of feed line), d_{12} = 0.5 mm (spacing between the resonators 1and 2), d_{13} =1.2 mm (spacing between the resonators 1 and 3).

Figure 6 shows the layout of the cross-coupled trisection bandpass filter and figure 7 shows the asymmetric response of the filter with high selectivity at the high side of the bandpass, low insertion loss and reasonable good rejection bands.

The simulation is carried out with the assistant of the full wave electromagnetic (EM) simulator CST MWS [7]. The simulations perform the substrate the dielectric constant, loss tangent, and the material of conductor are 10.8, 0.002, and copper with 0.035 mm thickness, respectively. The result is shown in Fig.7, along with the theoretical simulation results of the equivalent bandpass networks.

Excellent agreement between theoretical and simulation results is observed. The insertion loss is about 0.6dB and the in-band return loss is around 13.4 dB for the cross-coupled trisection filter. As expected, the transmission zero on the right side of the band is observed at 1.0936 GHz, with an out-of-band rejection of more than 25 dB at this point.

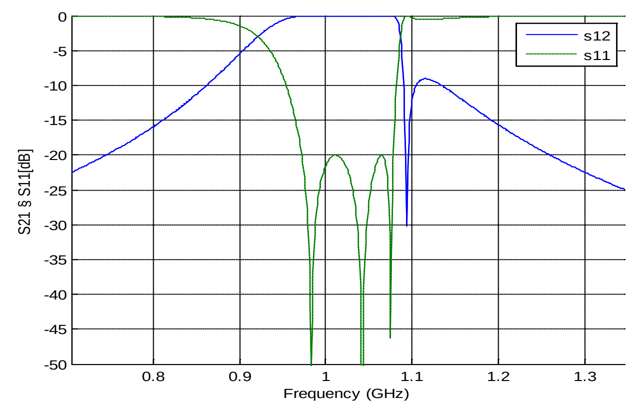

Fig. 5. Frequency response of the cross-coupled trisection filter with an attenuation pole on the high side of the passband.

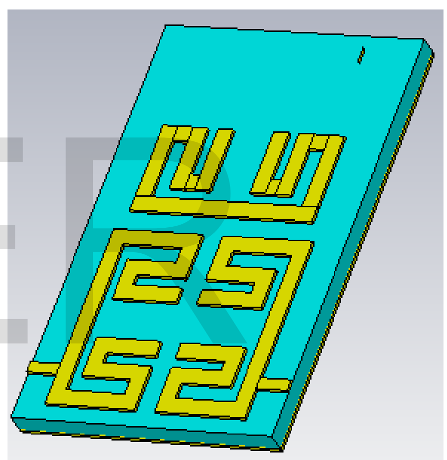

Fig. 6. Filter realization for a three-pole cross-coupled filter with finite frequency attenuation pole on one side of the passband.

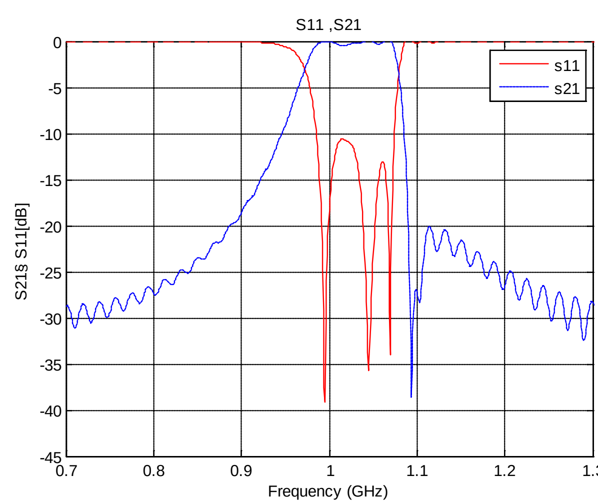

Fig. 7. EM simulation results of the proposed cross-coupled trisection filter.

4 Conclusion

This work describes design and analysis of a trisection open loop resonator bandpass filter with resonance frequency of 1.0251 GHz. The designed filter is numerically investigated by CST MWS software. Our proposed filter was implemented and was carried out for simulating reflection and transmission coefficients. Results are in agreement with those numerical and show that resonance frequency with low loss passband of −0.6 dB is obtained.

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