Compact Lowpass Filter with Stopband Using Radial Patch Resonators

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Abstract

Keywords: Lowpass Filter, Microstrip, Equivalent Circuit, Wide Stopband, Figure of Merit.

A compact elliptic-function low-pass filter using microstrip radial resonators and their equivalent circuit model are proposed. This filter is composed of multiple radial resonators and open stubs. To achieve wide stopband suppression, two symmetrically open stubs are adopted. Also equivalent circuit of the proposed filter is calculated according to high-low impedance lossless line, bend and open-end. A demonstration filter with 3 dB cut-off frequency at 1.64 has been designed, fabricated and measured. The results show that a relative stopband bandwidth of 175.3% (referred to suppression degree of 20 dB) is achieved, while obtaining high figure of merit of 33250. Also the proposed filter exhibits a small size of 0.165 λg × 0.074 λg, where λg is the guided wavelength at 1.64 GHz.

1. Introduction

Microstrip lowpass filters with compact size and high performances are one of the most important components in microwave circuits. They are used to separate or integrate different frequencies. There are a lots of techniques to achieve compact size and high performances simultaneously, one of the most important techniques are planer filters. Low cost, easy fabrication and combination with other microwave circuits are characteristics of this method. In filter [2, 3], to achieve an ultra-wide stopband, radial stubs and shunt open-stubs at the feed points of centre fed coupled-line hairpin resonator were used. A compact microstrip filter in [4] based on quasi-elliptic response was proposed. Both symmetrically loaded radial–shape patches and meandered main transmission line were used to achieve compact size. Although ultra-wide stopband and compact size were obtained, but the roll-off of the filter was not suitable [5, 6]. To achieve compact size and ultra-wide stopband, both triangular
patch resonators and radial patch resonators were employed in [5]. Also in [6], both triangular patch resonators polygonal patch resonators and meander transmission line were introduced to achieve ultra-wide stopband and reduce the circuit size. A novel microstrip lowpass filter using modified T-shaped resonator was presented to achieve a wide stopband and sharpness in transition band also to achieve sharpness in transition band, two T-shaped resonators were used in [7]. Authors in [8] presented a new microstrip lowpass filter with ultra-wide stopband, compact size and sharp roll-off using modified hairpin structures. In this paper, a novel lowpass filter with ultra-wide stopband and small size are presented. The filter has an ultra-wide stopband from 1.816 GHz up to 19.7 GHz stopband with an attenuation level better than 20 dB. The proposed filter exhibits low insertion loss in the passband about 0.2 dB and high return loss in the passband about 14.5 dB.

2. Lowpass Filter

Figure 1(a) shows the configuration of the proposed filter, which is composed of three radial patch resonators and rectangular shaped resonators. The equivalent LC circuit of the filter is shown in Figure 1(b) so that L2-L8 and C4, C5 and C7 are inductances and capacitances of high-low impedance lossless line. L1 refers to the inductance of the transmission line and C1, C2 and C3 are the sum of equivalent capacitances of bend and high-low impedance lossless line. Also C6 and C8 are the sum of equivalent capacitances of open-end and high-low impedance lossless line. The parameters related to these structures are L1=0.9 mm, L2=1.65 mm, L3=6.35 mm, L4=2 mm, L5=4.45 mm, L6=1.6 mm, L7=1.3 mm, L8=1.35 mm, L9=5.2 mm, L10=5.3 mm, L11=0.65 mm, L12=2.5 mm, W1=1 mm, W2=0.1 mm, W3=0.1 mm, W4=0.6 mm, W5=1.2 mm, T1=70 Deg., and T2=171 Deg.
A high-low impedance lossless line terminated at both ends with relatively low impedance lines can be presented by a Π-equivalent circuit, as shown in Figure 2. The values of inductors and capacitors can be attained as:

\[
l_s = \frac{1}{\omega} \times z_s \times \sin\left(\frac{2\pi l}{\lambda_g}\right)
\]

(1)

\[
c_s = \frac{1}{\omega} \times \frac{1}{z_s} \times \tan\left(\frac{\pi l}{\lambda_g}\right)
\]

(2)

Formulas of open-end have investigated here and its structure and equivalent circuit are shown in Figure 3.
Formulas of gap and bend have discussed and its structures and equivalent circuits are shown in Figure 4 that we have forwent their inductances because they are smaller than other inductances.

\[ C_p = \frac{\Delta f \sqrt{\varepsilon_r}}{c Z_o} \]  \hspace{1cm} (3)

\[ \Delta f = \frac{\xi_1 \xi_2 \xi_3}{\xi_4} \]  \hspace{1cm} (4)

\[ \xi_1 = 0.434907 \varepsilon_r^{0.81} + 0.26(w/h)^{0.8544} + 0.235 \]  
\[ \varepsilon_r^{0.81} - 0.189(w/h)^{0.8544} + 0.87 \]  \hspace{1cm} (5)

\[ \xi_2 = 1 + \frac{(w/h)^{0.371}}{2.3\varepsilon_r + 1} \]  \hspace{1cm} (6)

\[ \xi_3 = 1 + \frac{0.5274 \tan^{-1}[0.084(w/h)^{1.9413}\xi_2]}{\varepsilon_r^{0.9236}} \]  \hspace{1cm} (7)

\[ \xi_4 = 1 + 0.037 \tan^{-1}[0.067(w/h)^{1.456}]\{6 - 5\exp[0.036(1 - \varepsilon_r)]\} \]  \hspace{1cm} (8)

\[ \xi_5 = 1 - 0.218\exp(-7.5(W/h)) \]  \hspace{1cm} (9)

Fig.4: Layout and equivalent LC circuit of bend

\[ C(pF) = W(10.35\varepsilon_r + 2.5)\frac{W}{h} + (7.6\varepsilon_r + 5.64) \]  \hspace{1cm} (10)
The calculated and optimized values for LC equivalent circuit using above formula are summarized in Table 1.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
<th>C8</th>
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<tr>
<td>Optimized</td>
<td>0.06</td>
<td>0.19</td>
<td>1.26</td>
<td>0.2</td>
<td>0.77</td>
<td>0.95</td>
<td>10.3</td>
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<table>
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<tr>
<th>Parameters</th>
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<th>L3</th>
<th>L4</th>
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<td>Optimized</td>
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<td>4.22</td>
<td>1.11</td>
<td>3.5</td>
<td>0.42</td>
<td>0.08</td>
<td>0.49</td>
</tr>
</tbody>
</table>

Figure 5 shows the frequency response of the main resonator and LC equivalent circuit which they are in good agreement.

One of the features of the demonstrated resonator is that its cut-off frequency and transmission zeroes can be adjusted for different applications. Cut-off frequency and transmission zeroes can be modified with changing some of the resonator dimensions, these dimensions are \( L_6, \) \( W_4. \) They can control transmission zeros at 2 GHz, 9.8 GHz respectively that transmission zero at 2 GHz can modify cut-off
frequency. The simulated results of these resonators as a function of $L_6$, $W_4$ are shown in Figures 6 and 7, respectively.

![Fig.6: Simulated results as a function of L6](image1)

![Fig.7: Simulated results as a function of W4](image2)

**3. Simulation and Measurement Results**

Figure 9 shows the results of simulation and measurement which have been simulated and measured with an EM-simulator ADS and by an Agilent network analyzer N5230A respectively. Obviously, return loss and insertion loss are better than 14.5 dB and an insertion loss of less than 0.3 dB from DC to 0.8 GHz, respectively. The results exhibit that the stopband with 20 dB is from 1.21 to 26.35 GHz.
and sharpness in transition band is about 0.269 GHz (1.645 - 1.816 GHz with -3 and -20 dB, respectively).

Fig. 8: Simulated and measured S-parameters of the proposed lowpass filter

Fig. 9: Photograph of the proposed filter

Figure 9 shows photograph of the presented filter which has been fabricated on a substrate with a relative dielectric constant $\varepsilon_r=2.2$, thickness $h=20$ mil, and loss tangent $\tan \delta=0.0009$. The size of the fabricated LPF is obtained about $22\times9.9$ mm$^2$, which corresponds to an electrical size of $0.165 \lambda_g \times 0.074 \lambda_g$, where $\lambda_g$ is the guided wavelength at 1.64 GHz.

Among them, the roll-off rate is defined as:

$$\text{Roll-off rate} = \frac{\text{Bandwidth}}{\text{Transition Band}}$$
The relative stop-band bandwidth (RSB) is calculated by:

\[ RSB = \frac{\text{stopband bandwidth}}{\text{stopband center frequency}} \]  

(12)

The suppression factor (SF) is based on the stop-band bandwidth. For example, the stop-band bandwidth is referred to 20 dB suppression, thus the corresponding SF is defined as 2. A higher suppression corresponds to a greater SF. The normalized circuit size (NCS) can be derived as below:

\[ NCS = \frac{\text{physical size}}{\left(\frac{\text{length} \times \text{width}}{\lambda_g^2}\right)} \]  

(13)

where \( \lambda_g \) is the guided wavelength at 3 dB cutoff frequency. The architecture factor (AF) can be recognized as the circuit complexity factor, which is equal 1 when the design is 2D and as equal 2 when the design is 3D. Finally, the figure-of-merit (FOM) is the overall index of a proposed filter, is given by:

\[ FOM = \frac{\xi \times RSB \times SF}{NCS \times AF} \]  

(14)

As can be seen from Table 2, it clearly shows that the designed filter is superior to those reported in references.

**Table 2: Performance comparisons among published filter and presented one**

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Roll-off rate ( \xi )</th>
<th>Relative stopband bandwidth (RSB)</th>
<th>Suppression factor (SF)</th>
<th>Normalised circuit size (NCS)</th>
<th>Architecture factor (AF)</th>
<th>FOM</th>
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<td>[2]</td>
<td>30</td>
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<td>8789</td>
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<tr>
<td>[3]</td>
<td>95</td>
<td>1.4</td>
<td>2</td>
<td>0.11x0.021</td>
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<td>11951</td>
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<tr>
<td>[4]</td>
<td>36</td>
<td>1.32</td>
<td>1.5</td>
<td>0.07x0.07</td>
<td>1</td>
<td>11543</td>
</tr>
<tr>
<td>[5]</td>
<td>37</td>
<td>1.65</td>
<td>1.52</td>
<td>0.09x0.11</td>
<td>1</td>
<td>9065</td>
</tr>
<tr>
<td>[6]</td>
<td>22</td>
<td>1.55</td>
<td>1.5</td>
<td>0.08x0.08</td>
<td>1</td>
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</tr>
<tr>
<td><em>This work</em></td>
<td>85</td>
<td>1.75</td>
<td>2</td>
<td>0.074x0.165</td>
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<td>24365</td>
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</table>
4. CONCLUSION

A novel microstrip lowpass filter characterizing sharp roll-off and ultra wide stopband is presented using radial patch resonators. A prototype filter with -3 dB cutoff frequency 1.64 GHz is designed, fabricated and tested. Simulation and measurement results indicate that the proposed filter here achieves extremely high figure-of-merit of 24365 which is far exceeding that of the next best figure-of-merit of the latest works. With all these good features, the proposed filter is applicable to modern communication systems.

References