A stepped impedance resonator (SIR) based wideband bandpass filter (BPF) with a good rejection level in the extended upper stopband is presented in this article. The proposed SIR is found to have the ability to introduce two transmission poles in the passband. By appropriately selecting the impedance ratio and length ratio ($\alpha$) of the SIRs, the BPF can provide a wide passband and a sharp rejection over a broad stopband. Based on SIRs, a bandpass filter is designed with two transmission zeros. To improve the stopband, two stubs have been introduced in input/output (I/O) lines. The susceptibility test has been accomplished to check whether the filter will be able to operate satisfactorily in the presence of interfering signals. The filter has been fabricated and measured. Both simulated and measured results are presented.

1. INTRODUCTION

In the last decades, the growing proliferation of the wideband bandpass filters (BPFs) has been witnessed as they are the critical components for wideband devices. Among different types of available microstrip resonators, microstrip ring resonators found wide applications at microwave and millimeter-wave frequencies as they offer attractive features like compactness, dual resonance capability, and transmission zeros in the frequency response [1–3]. However, ring resonator suffers from dispersion when the ratio of ring width/ring radius becomes less than 0.2 [4]. In [5] the study of couplings between planar resonators in multilayer structures with modified (defected) ground plane has been reported with a good compactness. The wideband compact bandpass filter was presented by introducing the concept of dual-mode complementary split-ring resonator [6]. The C-shaped microstrip coupling feed structure was utilized for implementation of high-performance dual-mode configuration. Unfortunately, this kind of filter suffers from alignment problem during fabrication due to defected ground structure. Although multimode resonators [7–10], are the good candidates for wideband BPF design, such BPFs usually suffer from poor selectivity and spurious response. With the increasing demands for high signal quality and strong interference immunity, a broad stopband of the wideband BPF is highly desired. Recently, some novel approaches have been reported to improve the stopband of the wideband BPF, such as using short-ended resonators with centrally loaded inductive stubs [11], broadside-coupled microstrip/coplanar waveguide (CPW) and short-stub schemes [12], transversal resonators and asymmetrical interdigital-coupled lines concepts [13], coupled line sections [14], stepped impedance Hilbert fractal resonators [15], and transversal signal-interaction concepts and T-shaped structures [16]. Nevertheless, it is found that many of them also suffer from large electrical size.

Since an antenna is commonly the final component of a wireless (e.g., WLAN/WiMAX) microwave system [17, 18], microwaves bandpass filters are often subjected to microwave radiations. The radiated field from the antenna or nearby radiation sources can couple with the filter structure and may affect its characteristics. To avoid such interference, microwave circuits are often shielded. Such shield increases the circuit cost and also effect the circuit performance [19].

When the microwave circuits are incorporated into a system without shielding, knowledge of susceptibility of such structure is required. Therefore, in this paper, the susceptibility study of the filter has been done for both near field and far field sources.

In this article, a microstrip topology is proposed to realize quasi-elliptic wideband BPF with adjustable 3 dB fractional bandwidth (FBW). The proposed structure owns the tight coupling feed structure to provide a wider bandwidth. Moreover, by choosing proper series LC loads, multiple transmission zeros can be placed at the desired position to create a sharp roll-off rate at both the skirts, which gives good control over filter design. As compared to the previous topologies, the key advantages of this topology are the absence of defected ground structure (DGS) that makes the fabrication simpler.

2. FILTER DESIGN

Figure 1 shows the basic structure of a microstrip SIR which is constructed by joining two microstrip transmission lines with different characteristic impedances $Z_1$ (length, $L_1$) and $Z_2$ (length, $L_2$). The corresponding electrical lengths are $\theta_1$ and $\theta_2$, respectively and total electrical length is $\theta_T = \theta_1 + \theta_2$.

![Fig. 1 – The schematic diagram of microstrip SIR.](image)

Neglecting the discontinuity effects of microstrip step transition and the parasitic capacitance of the open-circuit port, the input impedance looking into the SIR, can be extracted using [20]:

\[ Z_{in} = \frac{Z_{oc}}{\theta_T} \]

\[ Z_{oc} = \frac{Z_1 Z_2}{Z_1 + Z_2} \]
Wideband bandpass filter using stepped impedance resonator

\[ Z_{OC} = Z_1 \left( \frac{Z_{OC} + jZ_1 \tan \theta_1}{Z_1 + jZ_1 \tan \theta_1} \right), \]  

(1)

where the input impedance of the open-circuit microstrip \( Z_{OC} \) can be expressed as:

\[ Z_{OC} = -jZ_2 \cot \theta_2. \]  

(2)

The resonance condition happens when

\[ Z_{in} = 0, \]  

(3)

Substituting eqn. (2) in eqn. (1) and then imposing the condition of eqn. (3), the resonance condition can be found as:

\[ K = \tan \theta_1 \tan \theta_2, \]  

(4)

where \( K = Z_1/Z_2 \). The resonator length \( \theta_1 \) has minimum value when \( 0 < K < 1 \) and maximum value when \( K > 1 \).

Resonance conditions of ordinary uniform impedance resonators (UIR’s) depend solely on the length of lines; whereas resonance condition of SIR’s depends on both the length and the impedance ratio. Therefore, SIR’s have more degree of freedom than UIR’s, and impedance ratio \( K \) is an important parameter in investigating SIR. For equal lengths of SIR \( L_1 = L_2 = 1 \) and given \( K \), the resonance condition can be given as:

\[ \theta_1 = \theta_2 = \theta_0 = \tan \sqrt{K}, \]  

(5)

and the fundamental resonance frequency can be calculated using [21]:

\[ f_0 = \left( \frac{c}{4L \sqrt{\varepsilon_{eff}}} \right), \]  

(6)

where \( c \) is the speed of light and \( \varepsilon_{eff} \) is the effective dielectric constant.

The simulated S-parameter magnitudes of stepped impedance open stub are shown in Fig. 2. It has been demonstrated that by changing the width ratio \( W_1/W_2 \) of the microstrip lines, which result in the modification of the value of \( K \), the position of the transmission zeros can be adjusted. If transmission zeros are moved to lower and higher passband edges, high selectivity can be achieved. It is evident from Fig. 2, that by increasing \( W_1/W_2 \), resonance frequency is varied.

The schematic of proposed SIR filter is illustrated in Fig. 3. The simulated frequency response of the magnitude of S-parameter is shown in Fig. 4.

![Fig. 3 – The schematic of the proposed wideband bandpass filter.](image)

It can be observed from the simulated results that there appears a notch at around 3.6 GHz in the upper stop band of the filter which degrades the filter performance. Therefore to improve the frequency response, two new stubs have been inserted in the feed line, as shown in Fig. 5.

The values of different dimensions of the filter are: \( L_1 = 17.5, L_2 = 16.6, L_3 = 12.3, L_4 = 4, W_1 = 0.5, W_2 = 17.2, W_3 = 0.5, W_4 = 1, g_1 = 0.4 \) and \( g_2 = 0.9 \) (all in mm).

The frequency response of the magnitude of S-parameter of the proposed filter, obtained from computer simulation technology (CST) and high frequency structure simulator (HFSS) software are shown in Fig. 6. Figure 6 reveals that three transmission poles are realized in the passband. The simulated result shows a 3dB fractional bandwidth of 67.4 % at the resonant frequency of 2.3 GHz (1.99–2.48 GHz) passband insertion loss of 0.58 and passband return loss better than 20 dB. The stopband has two transmission zeros and is extended to 6 GHz with a rejection level of 20 dB, which is 2.6 times of the fundamental frequency.

![Fig. 4 – The S-parameter of the proposed wideband bandpass filter.](image)
3. SUSCEPTIBILITY STUDY OF THE PROPOSED FILTER

The near-field and far-field susceptibility test of the filter has been performed to investigate the compatibility of the filter to work in a noisy environment. A patch antenna is used as an interference source, which generates the interfering signal. The interference source was placed at a distance $d$ from the plane under test (PUT) at an angle $\theta$ (with respect to the PUT) as shown in Fig. 8. Relative power ($P_r$) is used as a parameter to evaluate the susceptibility characteristics of the filter. The relative power is defined as a ratio of maximum interference power ($P_{\text{max}}$) to minimum interference power ($P_{\text{min}}$) measured with and without interference source, respectively. This can be expressed as:

$$P_r = \frac{P_{\text{max}}}{P_{\text{min}}}. \quad (7)$$

The filter was excited at port 1 with a signal of frequency, $f_c = 2.3$ GHz and power $P_c = -50$ dBm. To obtain a strong interference, the frequency of the interfering signal was also tuned at 2.3 GHz. The power level of the interference source ($P_i$), at the input of the antenna, was varied from 10 dBm to $-15$ dBm and the corresponding power transmitted through the filter was recorded at the output of the filter. The plot of interference power versus relative power is shown in Fig. 9. It is observed that $P_r$ decreases gradually as the power level of the interference source decreases, which is expected since the power level of the interference source, has a linear relationship with the logarithm of the noise level.
is kept only 10 mm away from the filter. In practice, this incident power is very high compared to its practical value as the filter will be subjected only to the radiation from the antenna connected to the system. Since the signal power within the filter is only −50 dBm, the incident power will be much less than −50 dBm due to the presence of path loss, antenna loss and the system losses. Thus the relative power will be much lower than 5, which indicate that the filter will work satisfactorily in the presence of interference from the antenna.

4. RESULT AND DISCUSSION

To validate the simulated result, the proposed BPF is fabricated on FR4 (relative dielectric constant $\varepsilon_r = 4.4$, loss tangent $\tan\delta = 0.02$) substrate with a thickness of 1.6 and copper thickness 0.035 mm. The measurement of the proposed fabricated filter has been carried out using Keysight PNA N5221A network analyzer. Both measured and simulated data are plotted and compared in Fig. 11, which show good agreement between them. The measured pass band is centered at 2.3 GHz with 3 dB fractional bandwidth of 67.4 %. The measured insertion loss is 1.4 dB and return loss is better than 20 dB. The transmission zeros are located at 1 GHz and 3.9 GHz. The fabricated filter is shown in Fig. 12.

Table 1 presents a performance comparison of the proposed wideband bandpass filter with some previously reported works. The insertion loss of the filter is a little bit poor due to chosen substrate i.e. FR4.

Table 1
Comparisons of the characteristics of proposed filter with other microstrip wideband filters

<table>
<thead>
<tr>
<th>Reference</th>
<th>$f_0$ (GHz)</th>
<th>FBW (%)</th>
<th>Insertion loss (dB)</th>
<th>Return loss (dB)</th>
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<tr>
<td>[3]</td>
<td>1.45</td>
<td>57.9</td>
<td>0.6</td>
<td>18.8</td>
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<td>[6]</td>
<td>2.23</td>
<td>62</td>
<td>0.27</td>
<td>12</td>
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<tr>
<td>[7]</td>
<td>2.2</td>
<td>37</td>
<td>0.5</td>
<td>22</td>
</tr>
<tr>
<td>[12]</td>
<td>5</td>
<td>40</td>
<td>0.7</td>
<td>17.1</td>
</tr>
<tr>
<td><strong>Our work</strong></td>
<td><strong>2.3</strong></td>
<td><strong>67.4</strong></td>
<td><strong>1.4</strong></td>
<td><strong>20</strong></td>
</tr>
</tbody>
</table>

5. CONCLUSION

In this article, a wideband BPF based on stub loaded resonators (SLR) has been proposed. A 67.4 % 3 dB fractional bandwidth has been realized with an insertion loss better than 1.4 dB. Compared to many other reported design, the proposed filter has a broader stopband. The filter has further advantages of having a simple structure and design procedure, which makes it good candidate for the modern wireless communication applications such as: mobile WiMAX 2.3–2.4 GHz, Wi-Fi 2.4–2.45 GHz and WLAN 2.4 GHz. The susceptibility test of the proposed structure indicates that the filter will work satisfactorily in the presence of the interfering source.

Received on April 28, 2016

REFERENCES


