Performance Enhancement of Miniaturized Dual-Band Bandpass Filter

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Abstract: Recently a significant design technique was proposed to develop miniaturized dual-band bandpass filters using multilayered dual-mode resonator. The attitudes of these filters show good performance with 3 GHz upper rejection band. In order to improve the stopband performance of these filters, this article presents a new generation of miniaturized dual-band bandpass filters having extra transmission zero in the upper stopband. The desired transmission zero is generated by electrical physical length (l₁) equal to a quarter-wavelength open-circuited stub resonator created from the filter structure itself. This is achieved by slipping down the input/output feeding ports from the far end connection points to the desired electrical length. To verify the proposed idea, a dual-band BPF operating at 1.9 GHz GSM and 3.5 GHz WiMax systems is designed, simulated and fabricated. The measured and simulated filter responses are in well agreed. It is observed that this filter has attenuation better than 15 dB over 5 GHz rejection band. The filter circuit area is very small of about 37 mm² terminating the feeding ports.

Keywords: Dual-band filter; short stub loaded resonator; upper stopband enhancement; dual-mode resonator; multilayer technology.

1. Introduction
The development of dual-band bandpass filters with wide rejection band are highly required to be compatible with the rapid requirements of an accurate multi-wireless communication system. Usually, the predictable response of an ideal dual-band BPF being without any spurious in the upper rejection band. However, one of the unwanted features for the distributed resonators is the generation of unrequired harmonics. These harmonics are considered as dispersed peeks in the upper rejection band. To eliminate these out of band peeks and enhance the response of the designed dual-band filter, different suggested techniques are utilized and reported in [1-11]. One of the most popular methods to suppress the unwanted higher frequencies is the defected ground structure (DGS) technique [1, 2]. In [1], two rectangular DGSs are etched between the input/output stubs and the dual-mode resonator arms to develop dual-band filter with wide rejection band. However, the resulted filter has poor selectivity. Using dumbbell and rectangular DGSs, the upper band of a dual-band BPF is improved kindly with complex large circuit size [2]. Based on a defected microstrip structure (DMS) technique, [3] proposed a dual-band BPF with wide stopband performance. Unfortunately, the filter stopbands performance improved with only two transmission zeros. Another technique used stepped impedance
stubs working as a lowpass filter integrated with the main structure of a dual-band filter to enhance the upper stopband performance [4]. However, the filter response shows very narrow bands with on attenuation pole. By adjusting the coupling length of the coupled stepped impedance resonators (SIRs), [5] designed ultra-rejection band dual-band bandpass filter with high in-bands insertion losses. In [6], the SIRs are loaded by open stub resonator to develop dual-band BPF with high performance upper rejection band. Moreover, dual-band filter with wide out-of-band rejection is achieved by choosing a desired impedance and electrical length ratios of quad-mode resonator in [7] and of half wavelength resonator in [8]. In addition, techniques to create two transmission zeros in the upper rejection band are significantly used to develop dual-band bandpass filters with deep attenuation over wide stopband [9-11]. In [9], a spiral stepped-impedance resonator loaded by a stub was utilized to present wide stopband dual-band BPF with high skirt roll off. Furthermore, the generation of transmission zeros in [10] made by increasing the length of the coupled lines firstly and by 0° feed structure later. The authors in [11] have presented a dual BPF based a dielectric rode with some of the modification getting compatible stopband rejection. In general, all the resulted filters of the so far presented techniques have quite large circuit size that may not satisfy the requirements of modern wireless communication systems.

This paper reveals a technique to significantly increase the upper stopband attenuation in the miniaturized dual-band filters, [12, 13], by introducing a transmission zero in the upper stopband. The basic concept of this technique based on generating a transmission zero to attenuate the unwanted harmonic response and hence the band rejection is improved. In order to save the circuit size of the filter, an electrical length equal to a quarter-wavelength open-circuited stub resonator needed to generate the required attenuation pole is created from the body filter circuit itself. To verify the proceeding concept, the design of a 2nd-order dual-band filter is explained and fabricated. The responses from the simulation and measurement are compared and discussed.

2. Multilayered dual-mode resonator for miniaturized dual-band BPF

A type of dual-mode resonators, the square-loop dual-mode resonator (SLDMR), is realized to develop a miniaturized dual-band bandpass filter for the multi-communication system of GSM/WiMAX applications [13]. In this example, the SLDMR schematic diagram, Figure 1 (a), is characterized as a short-circuited stub (l₂ & d₂) loaded square-loop resonator. In fact, the square-loop resonator is a half wave open-circuited stub resonator defined by 2l₁ and d₁. Due to its symmetrical shape, the even-odd mode analysis can be adopted to explain its resonance characteristic.

![Figure 1](image-url)  
**Figure 1.** (a) Conductor layout of the SLDMR, (b) Its equivalent circuit at odd-mode excitation, and (c) Its equivalent circuit at even-mode excitation.
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By exciting the structure, two equivalent circuits can be obtained as shown in Figure 1. When the odd-mode excitation is the dominant mode, the structure has an equivalent circuit, Figure 1(b), working at \( f_{\text{odd}} \) which represents the desired upper passband. In contrast, whereas the even-mode excitation is the dominant mode, the structure has an equivalent circuit, Figure 1(c), operating at \( f_{\text{even}} \) which represents the desired lower passband. Following the analysis steps in [14-15], the resonance frequencies can be cleared as:

\[
\begin{align*}
    f_{\text{odd}} & = \frac{c}{4l_1\sqrt{\varepsilon_{\text{eff}}}} \\
    f_{\text{even}} & = \frac{c}{4(l_1+l_2)\sqrt{\varepsilon_{\text{eff}}}}
\end{align*}
\]

Using the above information, the SLDMR is realized with two frequencies, \( f_{\text{odd}} = 3.5 \) GHz and \( f_{\text{even}} = 1.9 \) GHz. This structure is patterned on a 0.5 mm thick Rogers (RO3010) grounded substrate has a relative permittivity of \( \varepsilon_r1 = 10.2 \). The physical dimensions of the designed SLDMR, Figure 1 (a), are obtained and reported in Figure 2. Next, the dual-mode resonator is simulated using the momentum simulator of ADS program [16] and their responses are plotted in Figure 2. This Figure explains the imaginary part of the input impedance \( (Z_{in}) \) of the SLDMR with respect to frequency.

Figure 2. Impedance characteristic of the SLDMR, Figure 1 (a), with physical dimension of \( l_1 = 8.6 \) mm, \( l_2 = 4.75 \) mm, \( d_1 = 0.4 \) mm, and \( d_2 = 0.4 \) mm.

Based on the above analysed DMRs, a dual-band bandpass filter is developed using multilayer technology. Figure 3 (a) shows the filter conductor pattern in three-dimension geometry. On the first grounded layer, two SLDMRs are shorted to the ground and coupled using a separate gap \( (g_c) \) to specify the desired dual-band passbands, Figure 3 (a). In the same Figure, the second ungrounded layer consists of two short-circuited quarter wavelength stubs coupled through one via hole to achieve the filtering response. In this layer, the two \( \lambda/4 \) short-circuited stubs physical dimensions are \( d_1 = 0.4 \) mm and \( l_3 = 8.85 \) mm fabricated on Rogers (RO3010) ungrounded substrate with a dielectric constant of \( \varepsilon_r2 = 10.2 \) and a thickness of \( h_2 = 0.25 \) mm. Next, both filter circuits are capacitively coupled using broadside coupled microstrip lines of electrical length \( le = 4.6 \) mm. The 50-ohm input/output ports width of \( d_p = 0.6 \) mm are directly connected to the top far end of the top structure.
Finally, the developed filter is simulated using the momentum in ADS software, [16], and its response is improved at $g_c = 0.3$ mm as shown in Figure 3 (b). The overall operating behaviour of the dual-band bandpass filter may be investigated apparently with the aim of electrical current distributions. The current density at the lower/upper passband ($f_{even}/f_{odd}$) is rising towards the maximum value of the current at the surface and became lower at the stopband. This can be clarifying the very low insertion loss at the passband ($f_{even}/f_{odd}$) and high insertion loss in the stopband ($f > 4$). As shown in Figure 4 (a), at the lower passband ($f_{even}$) the overall length of the SLDMR activated with large following of surface currents proving the even-mode excitation, Figure 1 (c). However, at the upper passband ($f_{odd}$), Figure 4 (b), the external length of the SLDMR activated with strong flowing currents at the surface proving the odd-mode excitation, Figure 1 (b). At the stopband ($f = 5$ GHz) the overall SLDMR dose not following high currents at the surface, Figure 4 (c), and leaving high insertion loss.

**Figure 3.** (a) Three dimension layout structure of dual-band BPF based on SLDMR, and (b) its simulated S-parameter.
This Figure indicates that the resulted passbands have a second-order response with high isolation between two passband (-38 dB at 2.5-3.1 GHz) and good insertion/return losses about 0.03/21.55 dB and 0.07/17.62 dB at the first/second bands respectively. Also the filter offer high skirt selectivity resulted from the four transmission zeros around the desired passbands and reasonable upper rejection band exceeding 3 GHz.

![Figure 4](image)

**Figure 4.** (a) The current density distribution of the dual-band BPF at (1.9 GHz) (b) at (3.5GHz) (c) at (5 GHz).

3. **Enhancement to stopband performance**

In section 2, the dual-band BPF consisting of multilayered square loop dual-mode resonator was shown to have good in and isolated-bands performance. However, its -10 dB rejection at certain frequencies over the upper stopband (f > 7 GHz) can be a cause for concern. To tackle this problem the top layer topology of the filter in Figure 3 (a) is changed. The idea behind the change is to stop transmission resonances between 7 GHz and 8 GHz which are due to the unwanted harmonics of the distributed resonators in the filter structure in Figure 3 (a).

Consequently, an electrical length ($l_{TZ}$) equal to quarter-wavelength open-circuited stub resonator needed to generate the required transmutation zero is created from the body filter circuit itself. The required quarter-wavelength open-circuited resonator is determined on the top filter circuit by slipping down the feeding ports position to the desired electrical length. To achieve this concept properly, the unwanted frequencies must be first specified from the filters responses shown in Figure 3 (b). Then the physical length ($l_{TZ}$), Figure 5 (a), meeting the condition of the quarter-wavelength open-circuited resonator at these frequencies can be calculated. In this example, the feeding ports abduct from the far ends of the second filter circuit by a determined distance of ($l_{TZ} = 2$ mm) meeting the harmonic frequency condition of 7 GHz. Using the Momentum in ADS software, the insertion and return losses of the transformed filter over a wide band were computed and the results are depicted in Figure 5 (b). The simulated responses before and after improvement are compared and sketched in Figure 6. Obviously, the upper band rejection sufficiently enhanced with keep on the desired features of the filter unchanged.
Figure 5. (a) Three dimension layout structure of dual-band BPF with improved upper rejection band, and (b) its simulated S-parameter.
To demonstrate the above observation in practice, the developed dual-band filter is designed and fabricated on double Rogers (RO3010) substrate with a dielectric constant of $\varepsilon_r = 10.2$. The two circuits of the filter are photographically etched and then stacked together as one circuit, Figure 7 (a). The fabricated structure, Figure 7 (a), is applied with two SMA connectors and the measurement results are measured using (Anritsu MS4642A Vector Network Analyser (VNA)). As shown in Figure 7 (b), the resulted attitudes from measurement following the simulation result. Moreover, the upper stopband significantly improved with a maximum attenuation of 15 dB exceeding 5 GHz. Table 1 illustrates comparison in the filter’s broad characteristics of the simulated results with the recent reported works.

Table 1. Comparison with recently reported topologies.

| Ref. | Passbands (GHz) | Insertion loss, dB | Return loss, TZs (dB) | Size (mm²) | Improving technique | PCB fabrication | Attenuation between passband, dB |
|------|----------------|--------------------|----------------------|------------|---------------------|-----------------|---------------------------------|
| [2]  | 2.35/3.61      | 0.457/0.682        | 23.57/17.2           | Non        | > 266               | DGS             | < -20 without TZs               |
| [3]  | 2.4/5.6        | 0.5/1.1            | ≈ 31/18              | 2          | > 1400              | Loaded SIR     | < -70 with one TZ at 4 GHz      |
| [4]  | 3.5/5.7        | 1.1/0.89           | ≈ 14/16.8            | 2          | 228                 | SIR             | < -50 with one TZ at 4 GHz      |
| [6]  | 2.4/5.2        | 1.2/2.48           | > 16                 | 4          | > 710               | Loaded Stub-SIR| < -65 without TZs               |
| [7]  | 1.395/1.825    | 2.48/3.6           | ≈ 30/28              | 1          | > 2450              | Shorted stubs-SIRR| < -50 with one TZ at 1.65 GHz |
| [8]  | 3.5/5.25       | 1.87/2.33          | > 20                 | 2          | 513                 | Adjusting the electric length of SLR| < -40 with two TZs at 4.2-4.5 GHz |
| [10] | 2.4/5.2        | 0.36/1.0           | 17.4/15.8            | 6          | > 66                | RLR & 0° feed structure| < -25 with two TZs at 3.2-4.4 GHz |
| **This work** | **1.9/3.5** | **0.03/0.07** | **21.55/17.62** | **< 37** | **3 layer** | **4 open-stub from the same filter structure** | **-38 with two TZs at 2.5/3.1 GHz** |
4. Conclusion

A new generation of a miniaturized multilayered dual-band bandpass filter having extra transmission zero in the upper stopband was suggested in this paper. The attenuation pole was introduced to suppress the unwanted harmonics from 7 to 8 GHz and increase the filter stopband performance. In order to save the circuit size of the filter, the required transmission zero was generated using an electrical length meeting the condition of $\lambda/4$ open-circuited stub resonator created from the same body of the filter circuit. To verify the proposed idea, a prototype was manufactured and measured. The filter simulation and measurement were compared and discussed. However, the upper band rejection was fully extended with attenuation better than 15 dB exceeding 5 GHz. The designed filter has a very compact surface area smaller than 37mm$^2$ terminating the feeding ports.

Figure 7. (a) A photograph of the dual-band BPF based on SLDMR with improved upper stopband, Figure 5 (a) and (b) its simulated and measured $s$-parameters.
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