Improvement of Transmission Characteristics in Multilayer Dual Band Filter

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**A R T I C L E  I N F O**

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**A B S T R A C T**

This paper first simplifies the GA-optimized filter structure developed by us. Then the filter structure is modified by introducing slot and conductor stubs, based on electric fields and magnetic currents at resonant and transmission zero points. As a result, return losses in two passband regions are suppressed more than 28 dB, and also insertion loss in stopband dividing two passbands is suppressed more than 20 dB. Finally, two kinds of the proposed filters are fabricated, and effectiveness of them is confirmed from comparison between the measured and the numerical results.

1. Introduction

This paper is an extension of work originally presented in 2017 Asia Pacific Microwave Conference, (APMC2017) [1]. Based on our work in [2], the goal is to develop high-performance UWB bandpass filter.

In recent years, wireless communication systems such as wireless local area network (LAN) and mobile terminals have spread rapidly. High-frequency filters are used to extract a signal of a desired frequency band for the purpose of prevention of unnecessary radiation and interference. Increasing in complexity and volume of wireless communication, a filter having a large attenuation amount close to pass band and an improved insertion loss is indispensable. Conventional resonant elements that have been developed to achieve high performance such as improved multi-band sharing and attenuation characteristics outside a pass band required for the wireless communication device are not sufficient. Therefore, development of a new resonant element desired. Under such circumstances, we have proposed the ultra-wideband (UWB) filters, of which conductor patches and slot shapes were optimized under the genetic algorithm (GA) technique [2]. As for UWB filters, many filter structures have been developed [3-17]. They are essentially based on the multi-mode resonators (MMR) which were first developed in [3]. Then, various stub-loaded resonators were often used to achieve good skirt selectivity and compact size [4-7]. To perform further good filter performance, the resonator shapes including a stepped-impedance technique were investigated [8-17]. The planar circuit filter designed by GA shows the desired characteristics according to the evaluation function, but the return loss there was not so high (about 10 dB). In addition to the problem of calculation capacity and computation time, the circuit element shape is complicated and the degree of freedom is small, so that it is difficult to improve the filter characteristics by slightly modifying the GA-optimized filter shape.

In this work, we clarify resonant mechanism and transmission zero mechanism of the UWB filter optimized by the GA. Then, the simplified filter structure based on the their mechanisms is proposed. Furthermore, to improve loss characteristics between two passbands of the dual-band filter, the conductor and slot stubs are newly loaded. Validity of the proposed filter is also verified experimentally.

The rest of this paper is structured/organized as follows: Section 2 discusses resonant mechanism of the UWB filter; Section 3 presents improvement of filter transmission characteristics; Section 4 verifies effectiveness of the proposed filter; and finally, in Section 5, we summarize the conclusions derived from this work and indicate possible future works.

2. Simplified filter generated by GA

New planar circuit filters have been developed by GA evaluated characteristics of both passband and stopband [18-19]. In this section, we briefly describe the structure of the multilayer planar circuit filter and the outline of the optimized design by the GA of the planar circuit filter [18-19]. After the circuit shape and filter characteristics are described, we simplify the filter based on resonant principle.
2.1. Structure of the GA-optimized UWB filter

Figure 1 shows the UWB-filter structure developed by us. This filter optimized by GA consists of slot elements on the ground plane and patch elements on the conductor-backed dielectric substrate ($\epsilon_r = 2.2$, thickness $t_2 = 0.51$ [mm]). Both elements have arbitrary shapes and the filter is covered by the shielding box ($a = b = 15.2$ [mm], $c = 20.0$ [mm]). Input and output of the filter are connected through a microstrip line. A lot of resonances are mainly caused by slot elements.

![Arbitrarily-shaped slot](image1)

**Figure 1.** Structure of the GA-optimized UWB filter.

![GA-optimized region](image2)

**Figure 2.** An example of an arbitrarily-shaped element constructed by uniform mesh.

2.2. Shape of the GA-optimized UWB filter

As shown in Fig. 2, the planar circuit shape is represented by a set of conductor patch cells and handled by binary codes of "0" and "1" in the optimized design method by GA [3]. The analysis is performed by the moment method. In the design, the symmetrical structure on the yz plane of $x = a/2$ is assumed and the shape of the input/output line is fixed. The parameters for optimization by GA are set as follows. The $x$ planes at $z = t_1$ and $t_1 + t_2$ are divided into 20x20 cells, and the size of one cell is 0.76 mm. The evaluation frequency bands are 3.4–4.8 GHz, and 7.25–10.25 GHz in the passband, while 1.0–3.0 GHz, 5.0–7.0 GHz, and 10.35–14.0 GHz in the stopband, and the target of the return loss in the passband and the insertion loss in the stopband are set as 10dB. The mutation rate is 0.02 and the crossover rate is 0.8. The generation number is 400, the population size of one generation is 50, and the elitist strategy is applied.

![Patch shape](image3)

**Figure 3.** Shape of the GA-optimized UWB filter.

![Electric-field distribution at each resonance](image4)

**Figure 4.** Frequency characteristics of the UWB filter optimized by GA.

![Electric-field distribution at each resonance](image5)

**Figure 5.** Electric-field distribution at each resonance.

2.3. Resonant mechanism

Resonances are mainly caused on the slot face, so we observe the electric-field distributions on the slots. Figure 5 shows the electric field on the slot at each resonant point. Resonance at 3.6 GHz shown in Fig. 5 (a), is the half-wavelength even resonant mode of the upper-part slot. Resonance at 4.5 GHz in Fig. 5 (b) is the half-wavelength odd resonant mode of the two slots arranged symmetrically for the center line. Resonance at 7.6 GHz in Fig. 5 (c) is the half-wavelength even resonant mode of the lower-part slot. Resonance at 9.6 GHz in Fig. 5 (d) is the odd resonant mode that is the next higher-order one of the resonance at 4.5 GHz. Resonance at 10.1 GHz in Fig. 5 (e) is the 3/2-wavelength even...
resonant mode that is the higher-order one of the resonance at 3.6 GHz. From the above-mentioned guess of the resonant mechanism, we first calculate the frequency characteristics for the simplified structure shown in Fig. 6 (a) and (b). Its frequency characteristic is shown in Fig. 7, where four resonant points are produced corresponding to the first, the second, the fourth and the fifth resonant points in Fig. 4. Figure 8 (a) and (b) also show another simplified structure and its frequency characteristic is given in Fig. 9, where one resonant point is produced corresponding to the third resonance in Fig. 4. Then we combine these two basic simplified structures and adjust the filter characteristics to the UWB filter by adding slot stubs and microstrip patches and also by modifying the slot junction part. As a result, Fig. 10 (a) and (b) are obtained as a simplified filter structure and the enlarged part of the slot junction is also shown in Fig. 10 (c). The dimensions are listed in Table 1. The slot width is 0.76 mm. Figure 11 shows the frequency characteristics of the simplified UWB filter. Five resonances are reproduced near the original resonant frequencies shown in Fig. 4. Figure 12 shows the magnetic currents at the resonant point to confirm the resonant mechanism. It is clear from this figure that the simplified filter structure works by the same resonant mechanism with that of the GA optimized filter. However, the insertion loss in the stopband is not so high less than 20 dB. So we improve it by considering mechanism of the transmission zeros in the next session.

Table 1. Dimensions of the patch and the slot parameters (unit: mm).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p_1 )</td>
<td>1.52</td>
</tr>
<tr>
<td>( p_2 )</td>
<td>0.76</td>
</tr>
<tr>
<td>( p_3 )</td>
<td>1.78</td>
</tr>
<tr>
<td>( p_4 )</td>
<td>2.24</td>
</tr>
<tr>
<td>( p_5 )</td>
<td>3.61</td>
</tr>
<tr>
<td>( p_6 )</td>
<td>1.04</td>
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<tr>
<td>( p_7 )</td>
<td>1.52</td>
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<tr>
<td>( p_8 )</td>
<td>2.78</td>
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<td>( p_{10} )</td>
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</tr>
<tr>
<td>( p_{11} )</td>
<td>1.42</td>
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<tr>
<td>( p_{12} )</td>
<td>0.74</td>
</tr>
<tr>
<td>( p_{13} )</td>
<td>2.58</td>
</tr>
<tr>
<td>( g )</td>
<td>0.74</td>
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<tr>
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<td>( s_{11} )</td>
<td>3.06</td>
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<tr>
<td>( s_{12} )</td>
<td>0.46</td>
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</table>

The slot width is 0.76 mm.
3. Improvement of stopband characteristics

We can see five transmission zeros within 12 GHz in Fig. 4. Among these transmission zeros, the first and second zeros can control by slight modifications of the filter shape, which have little influence for the passband characteristics. We first take notice of the transmission zero at 2.0 GHz. This transmission zero may be caused by the cancellation due to the direct coupling between the input and the output microstrip line through the gap g shown in Fig. 13 (a). Figure 13 (b) shows the transmission characteristics for varying the value of the gap g. As expected, only the first transmission zero greatly moves, depending on g. It is clear that the gap g is a useful parameter for controlling the frequency point of the first transmission zero. Next, we notice of the second transmission zero of 5.5 GHz. Figure 14 shows the magnetic-current distribution at 5.5 GHz. We can see from this figure that the magnetic current strongly flows in the center slot connecting between the lower-part and higher-part slots. Therefore, if the slot stub is loaded into the center slot, the transmission zero at 5.5 GHz can move independently.

Figure 14 shows the slot stub of the length $L_1$ and the other parameters are $s_{17} = 0.33$ [mm], $s_{18} = 0.30$ [mm], $s_{19} = 0.33$ [mm]. Figure 16 shows the frequency characteristics for varying $L_1$. Although only the second zero point shifts to the higher frequency region with increasing $L_1$ and the stopband characteristic is improved as expected, the third resonant point also moves to the higher region, and the passband characteristic slightly deteriorates. The third resonance at 7.6 GHz is generated by the bottom slot as mentioned in Sec. 2, but if the length of the resonator is made longer, the second and the forth resonances also a little bit move, so such a deformation of the bottom slot for characteristic improvement is difficult. Therefore, we install a small projection of the length $L_2$ in the upper slot resonator shown in Fig. 17. The projection is coupled with the lower slot resonator so that only the

![Figure 12](image1.png)

Figure 12. Magnetic-current distribution at each resonance.

![Figure 13](image2.png)

Figure 13. Frequency for various gap $g$.

![Figure 14](image3.png)

Figure 14. Magnetic-current distribution at 5.5 GHz.

![Figure 15](image4.png)

Figure 15. Parameters of the slot stub.

![Figure 16](image5.png)

Figure 16. Frequency characteristics for various slot stub length $L_1$. 

![Figure 17](image6.png)

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third resonance can move. Figure 18 shows the transmission characteristics for varying value of $L_2$. Clearly only the third resonance moves and other resonances, and the transmission zero points don’t move. Furthermore, two small conductor stubs are loaded on the input/output line in order to improve the transmission characteristics at around 10 GHz as shown in Fig. 19. Figure 20 shows the transmission characteristics of the filter proposed under the above-mentioned investigation and, the return losses in the two passbands are suppressed to 28 dB, and the insertion loss in the stopband is suppressed to 20 dB or more. Most of UWB filters do not reach to these-losses levels in three pass and stop bands.

Figure 21. Measurement system.

Figure 22. Photograph of the simplified filter.

Figure 23. Measurement frequency characteristics of the simplified filter.

Figure 24. Photograph of the proposed filter.
Conflict of Interest

The authors declare no conflict of interest.

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References

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