A compact high-selective dual-band pass filter

Dongya Cheng¹, J Wang², C Y Jin¹, K F Cui¹ and M Q Li¹
¹College of electronic information engineering, AnHui University, anhui hefei 230601, china.
²Electro-Mechanical Engineering Institute, Beijing 100074, China.
E-mail: AHU411MHz@hotmail.com.

Abstract. A compact high-selective dual-band pass filter is designed. The first passband is created by complementary open resonant ring defect ground structure, and the second is created by open circuit branch resonator. The presented design has advantages of steeper edge attenuation ramp, lower in-band insertion loss, better out-of-band rejection levels, and has compact structure. The center frequencies of dual bands are 2.4 GHz and 3.4 GHz, 3 dB bandwidths are 33 MHz and 32 MHz, and return loss is -36.36 dB and -36.07 dB. The first frequency band can be applied to the microwave interconnection access, and the second can be applied to WLAN, two passband has better isolation.

1. Introduction

With the rapid development of information science and technology, wireless communication technology has also made great progress. Among them, the filter is a very important part of the mobile communication system. It is responsible for frequency selection of the wireless transmitting and receiving ends in the wireless communication system, mainly for filtering out interference and clutter of the transmitting and receiving channels. However, frequency resources are becoming increasingly tight. In order to improve the utilization of spectrum resources, dual-band filters are becoming more and more important [11].

Traditional multi-band filters are mostly connected by multiple single-band filters, but this method requires duplexing and other devices to match, which increases the complexity of the system and increases the volume of the system. In contrast, the use of a dual-band filter can reduce the volume of the filter and reduce the loss. There are many ways to implement dual-band communication, such as the use of stepped impedance resonators (SIR), defective ground structures (DGS), dual-mode resonators, and the introduction of transmission zeros on broadband single-frequency filters [8]. The defect structure was first proposed by JL Park et al. in 1999. It refers to etching a groove of a certain shape on the floor, thereby changing the current flow on the floor, changing the equivalent capacitance and equivalent inductance of the floor and general passband characteristics.

The dual-band pass design is using a complementary open-circuit branch resonant ring and an open resonant ring defect ground structure. The defect ground structure can also improve the selection characteristics of the filter, making the curve steeper, improving the quality factor and rectangular coefficient of the filter, and also facilitating the miniaturization of the filter, making the structure more compact [4].

2. Dual band pass filter design
The dual band pass filter is composed of an open-circuit branch resonant ring and complementary open resonant ring defect ground structure. The open-circuit branch resonator ring consists of an open resonant ring and a shorted stub. The resonator is equivalent to a second-order tuned circuit. When the same selectivity is achieved, the order is only half of the original, and the miniaturization can be achieved at the same time to generate the second passband [7]. The DGS structure changes the electric field distribution on the floor, allowing signals in some frequency bands to pass with minimal loss, resulting in a band gap with passband characteristics [2]. The reason why the defective structure has such a characteristic is the DGS structure introduces an inductor and a capacitor. In this paper two complementary open resonant rings are introduced to generate the first passband [5] [6] [9].

A dual-band pass filter was designed on a Rogers RT 5880 dielectric substrate with the relative dielectric constant of 2.65. The structure of filter is shown in Figure 1 and the dimensions of the various parameters in the figure are shown in Table 1. The equivalent circuit is shown in Figure 2 [1] [10], feeder lines are equivalent to the inductance L1, L3, equivalent capacitance between the feeder and the resonator are C1, C6. The equivalent capacitance between the open branch resonator and the floor are C2 and C5. The open-circuit branch resonator is equivalent to C4 and L5, the resonator's own coupling capacitor and coupled inductor is C7, L2. The complementary open resonant ring is structurally equivalent in inductance and capacitance is L4 and C3. The center frequency of the pass band are obtained by equations (1) and (4), and the transmission zero point is obtained by equations (2), (3), and (5) [3].

The model is simulated and adjusted by HFSS software. When the parameters of the filter structure are changed, the corresponding equivalent capacitance or inductance will be changed, and the simulation result will also change. Therefore, we can adjust the center frequency and bandwidth of the passband by adjusting the parameters of the filter to achieve the desired result. The adjustment process of the parameters is shown in Figures 3, 4, 5 and 6.

![Figure 1. Structure diagram of dual frequency band pass filter.](image)

![Table 1. Dimension table of structural drawing.](table)

| Parameter | Value     |
|-----------|-----------|
| L1        | 10mm      |
| A1        | 4.588mm   |
| A2        | 2mm       |
| A3        | 3.5mm     |
| A4        | 4.5mm     |
| A5        | 2mm       |
| A6        | 2mm       |
| K1        | 6.5mm     |
| K2        | 3.5mm     |
| n1        | 2mm       |
| n2        | 2mm       |
| m1        | 15mm      |
| m2        | 15mm      |
| m3        | 8.7mm     |
| m4        | 8.7mm     |
| P         | 0.5mm     |
Figure 2. Equivalent circuit diagram of a double-frequency band pass filter.

\[
f_1 = \frac{1}{2\pi \sqrt{C_1 L_5}}
\]

\[
f_{s1} = \frac{1}{2\pi \sqrt{(C_1 + C_3) L_5}}
\]

\[
f_{s2} = \frac{1}{2\pi \sqrt{C_2 L_2}}
\]

\[
f_2 = \frac{1}{2\pi \sqrt{C_1 L_4}}
\]

\[
f_{s3} = \frac{1}{2\pi \sqrt{(C_2 + C_7) L_4}}
\]

Figure 3. The relationship between transport characteristics and \( k_1 \).

Figure 4. The relationship between transmission characteristics and \( m_3 \) and \( m_4 \).

Figure 5. The relationship between transport characteristics and \( A_3 \).

Figure 6. Relationship between transmission characteristics \( L_4 \).

Figure 3 and Figure 4 are analyzed of \( k_1 \), \( m_3 \), and \( m_4 \) of the defective ground structure respectively. When \( k_1 \) is increased, the opening of the outer open resonant ring becomes smaller, the equivalent capacitance \( C_3 \) becomes larger, and the resonant frequency of the first frequency band becomes smaller. While there has little effect on the second passband. When \( m_3 \) and \( m_4 \) increase, the side length of the small open resonant ring becomes larger, the spacing between the complementary open resonant rings becomes smaller, and the equivalent inductance \( L_4 \) becomes larger, so that the resonant
frequency of the first frequency band is decreasing. While there has little effect on the second passband.

Figure 5 and Figure 6 show the A3 and L4 of the open-circuit branch resonant ring. When A3 increases, the equivalent inductance L5 decreases, and the internal coupling capacitors C7 and L2 are decrease. The second resonant frequency will increase, the second passband will shift to the right, and the transmission zero will also shift to the right with little effect on the first passband. When L4 is increased, the shorting branch will become longer, and the equivalent inductance L5 will increase, which will make the second resonance point smaller and have little effect on the first passband.

It can be seen from the above analysis that the first passband and the second passband can be independently controlled by adjusting corresponding parameters, so that we can analyze and optimize the filter according to our needs to obtain the dual-band pass filter we want. By adjusting the parameters, the dual-frequency band pass filters with the center frequencies of 2.4 GHz, 3.4 GHz was realized, and the bandwidth of -3 dB was 33 MHz and 32 MHz respectively, and the return loss was -36.36 dB and -36.07 dB respectively. The simulation figure is shown in Figure 12. As can be seen from the figure, the dual-band pass filter has a steep edge, has a good frequency selectivity, and has a significant stop band between the two pass bands, and the stop band rejection is greater than 25 dB.

3. Equivalent circuit analysis
All LC filters can be converted from low-pass prototype filters. The equivalent schematic of the dual-band pass filter shown in Figure 1 is no exception. It can be converted from the m-derivative low-pass prototype filter (shown in Figure 7).

![Figure 7. Deductive low-pass filter basic unit of m.](image)

![Figure 8. Schematic diagram of equivalent deductive low pass filter.](image)

\[
m = \sqrt{1 - \frac{f_r^2}{f_c^2}} \tag{6}
\]

\[
L_{01} = m \cdot \frac{Z_0}{2\pi f_c} \tag{7}
\]

\[
L_{02} = \left(1 - \frac{m^2}{m}\right) \cdot \frac{Z_0}{2\pi f_c} \tag{8}
\]

\[
C_{01} = \frac{m \cdot 1}{2\pi f_c Z_0} \tag{9}
\]

The specific parameters of the low-pass prototype filter can be calculated by equations (6)(7)(8)(9), where \(f_c\) is the cutoff frequency, \(f_r\) is the notch frequency, and the \(Z_0\) is characteristic impedance of the filter. Figure 8 is a schematic diagram of the equivalent m-type low-pass prototype filter of this filter. It can be seen from the figure that the filter is composed of two low-pass prototype filters, and the capacitance between the two filters is the coupling capacitor of the filter. Since the normalized low-pass filter has a cutoff frequency of \(1/2\pi\) HZ and characteristic impedance of 1\(\Omega\). So that the cutoff frequency is transformed to make the bandwidth of the low-pass prototype filter same as the designed bandpass filter, as in equations (10), (11), (12), and then the impedance transformation is converted as a formula (13), (14), (15), and finally the conversion from the low-pass filter to the bandpass filter is shown in Figure 9, the left side of the figure is the conversion device, the right side of the
Figure 9. Device conversion correspondence

Since the floor and the upper surface are mainly electrically coupled, they can be equivalent to a capacitor. The final equivalent circuit diagram is shown in Figure 2. The schematic diagram is simulated by the Advanced Design System software. The initial parameters obtained by calculation are shown in Table 2. The simulation results can be obtained by parameter optimization shown in Figure 11. The two center frequencies are 2.43GHz and 3.45GHz respectively. The 3dB bandwidth is about 35MHz and 37MHz respectively, the schematic simulation and model simulation results are basically the same.

Table 2. Parameters of equivalent circuit diagram.

|   | L1  | L2  | L3  | L4  | L5  | L6  | L7  | L8  | L9  | C1  | C2  | C3  | C4  | C5  | C6  | C7  | C8  | C9  | C10 |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|   | 22.2nH | 1.0nH | 1.0nH | 1.0nH | 0.5nH | 1.0nH | 1.0nH | 1.0nH | 0.5nH | 15.5pF | 17.7pF | 1.7pF | 4.7pF | 1.0pF | 0.3pF | 1.8pF | 1.8pF | 1.8pF |
4. Conclusion

In this paper, the complementary open resonant ring defect ground structure and the open-circuit branch resonator are combined into a dual band pass filter. The defective ground structure and the open branch resonator generate a pass band respectively. By applying the defect ground structure, the size of the filter structure is reduced, the edge is dropped very steeply, and achieving high selectivity. Through the coupling analysis of the filter, the equivalent circuit schematic is obtained, and the calculation formula of the resonance point and the transmission zero point is obtained. In this paper, the filter model is optimized and analyzed, and parameters which have a great influence on the filter are obtained. The parameters are adjusted to finally obtain the ideal compact high-selective dual-band pass filter. The equivalent circuit diagram of the filter is simulated, and the results are consistent with the model simulation basically. The overall size of the filter model is 32.8*34mm.

Acknowledgments

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