A New Design Method of Microstrip Dual-Band Bandstop Filters

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Abstract — A generic lumped-element circuit of dual-band bandstop filter (DBBSF) is proposed based on novel composite shunt resonators, and its design method is developed with closed-form formulas. As an example, a DBBSF with center frequencies of 1.7 and 2.3GHz is designed and fabricated using microstrip lines. The measured frequency response agrees excellently with the theoretical predictions, validating well the proposed design theory and filter structure.

Index Terms — Bandstop filter, dual-band, composite shunt resonator, microstrip line

I. INTRODUCTION

In recent years, a large number of papers on dual-band bandpass filters have been reported [1]-[3] in order to meet the increasing need for multi-band and multi-mode wireless communication systems. On the other hand, a dual-band bandstop filter (DBBSF) may have lower transmission loss and group-delay in its passband formed between its two stopbands, compared with a conventional bandpass filter. It can also be used to reduce effectively the distortion of signals at the output of a high-power amplifier (HPA) because of its double-side rejection bands [4]. The authors of [4] proposed a synthesis method of DBBSF by performing frequency transformations two times. This method assumed that the center frequencies of the dual-stopbands are very close to each other, and that the dual stopband bandwidths are equal. These assumptions constrict seriously the effectiveness and applications of this method.

In this paper, a novel generic circuit of DBBSF is proposed first by using lumped-element composite shunt resonators, and an approximate design method of it is developed. Both the midband frequencies and the bandwidths of the dual stopbands of the filter can be controlled separately. In Section II, the characteristic of a composite shunt resonator is described, and the circuit and design formulas of a DBBSF using composite shunt resonators are developed. In Section III, a 2-degree microstrip DBBSF with center frequencies of 1.7 and 2.3GHz is designed by using an electromagnetic simulator. The measured frequency response of the filter shows good agreements with the theoretical prediction.

II. DESIGN METHOD OF DBBSF

We provide first the design formulas of a conventional bandstop filter. Fig.1 shows a generic circuit of an n-degree BSF using conventional series LC resonators and admittance inverters. The parameters, including the inductor \( L_i \), capacitor \( C_i \), and admittance-inverter \( J_{ir} \), are related by the following well-known formulas [5].

\[
L_{iy} = \frac{1}{\omega_0 C_{ir}} \quad (i=1 \text{ to } n), \quad \Omega_0 = 1 \text{ (rad/sec)}, \quad (1)
\]

\[
J_{0i} = \frac{\omega_0 G_0 C_{ir}}{\text{FBW} \cdot \Omega_0 g_{ir0}} \quad J_{i,n+1} = \frac{\omega_0 C_{ir} G_{nn+1}}{\text{FBW} \cdot \Omega_0 g_{n+1}} \quad (2)
\]

\[
J_{i,n+1} = -\frac{\omega_0}{\text{FBW} \cdot \Omega_0} \frac{C_{ir} C_{r,i+1}}{g_{i} g_{i+1}} \quad (i=1 \text{ to } n-1) \quad (3)
\]

where \( \omega_0 \) is the midband angular frequency of the BSF, \( \text{FBW} \) is the fractional bandwidth, and \( g_i \) (i=0,1, ..., n+1) is the element values of a Butterworth or Chebyshev prototype lowpass filter.

\[
\begin{align*}
G_0 & : & J_{0i} & = \frac{2}{C_{ir}} L_{i} & = C_{ir} & \quad J_{12} & = \frac{2}{C_{r}} L_{12} & = C_{r} & \quad J_{23} & = \frac{2}{C_{r}} L_{23} & = C_{r} & \quad J_{n,n+1} & = \frac{2}{C_{r}} L_{n} & = C_{r} & \quad G_{nn+1} &
\end{align*}
\]

Fig. 1    Bandstop filter using series LC resonators and J-inverters.

Fig. 2(a) shows a composite shunt resonator [6]. It has two series LC resonators connected in parallel. It exhibits two anti-resonances at \( \omega_a \) and \( \omega_b \), respectively, and a resonance at \( \omega_0 \). Assume \( \omega_a < \omega_b \), then at frequencies between \( \omega_0 \) and \( \omega_b \), i.e., when \( \omega_a < \omega < \omega_b \), the composite resonator in Fig. 2(a) can be approximated by a shunt LC resonator shown in Fig. 2(b), which resonates at \( \omega_0 \). The equivalence equations between these two types of resonators are given below [6].
\[ L_s = \frac{2L_a L_b}{L_a + L_b} , \quad C_s = \frac{1}{\omega_0^2 L_s} \]

\[ L_s \left[ 1 - \left( \frac{\omega_s}{\omega_0} \right)^2 \right]^2 - L_s \left[ 1 + \left( \frac{\omega_s}{\omega_0} \right)^2 \right]^2 \]

\[ \omega_s = \frac{1}{\sqrt{L_s C_s}} \cdot \omega_0 = \frac{1}{\sqrt{L_s C_s}} \cdot \omega_0 = \frac{1}{\sqrt{(L_a + L_b) C_s}} \quad (6) \]

\[ X \begin{array}{c} \omega_a \\omega_b \\omega_c \end{array} \]

\[ \begin{array}{c} L_a \\omega_a \\omega_c \\omega_0 \end{array} \]

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Fig. 2 (a) A composite shunt resonator having two series LC resonators, and (b) its equivalent shunt LC resonator at frequencies close to \( \omega_0 \).

![Frequency response of a composite shunt resonator](image)

Fig. 3 Frequency response of a composite shunt resonator.

Fig. 3 shows a typical frequency response of the composite shunt resonator shown in Fig. 2(a). Two stopbands around \( \omega_a \) and \( \omega_b \) are observed, and they are caused by the resonances of the two LC series resonators. Meanwhile, a passband is formed around \( \omega_0 \).

As stated above, a composite shunt resonator exhibits dual stopbands around two anti-resonance frequencies. This property of a composite shunt resonator is utilized to build a novel dual-band bandstop filter circuitry. First, we replace all the series LC resonators in Fig. 1 with composite shunt resonators shown in Fig. 2(a). As a consequence, a new filter shown in Fig. 4(a) is obtained. Let all the \( L_a C_n \) \((i=1,2,\ldots,n)\) series resonators resonate at \( \omega_0 \), then stopband 2 around \( \omega_b \) is formed. Therefore, the circuit in Fig. 4(a) is a filter possessing dual stopbands.

Next, we describe design considerations of this \( \text{DBBPF} \). Assume \( \omega_a < \omega_b \). Since all the \( L_a C_n \) series resonators (i.e., the left-handed series resonators of the composite resonators) in Fig. 4(a) resonate at \( \omega_a \), their impedances are close to zero at frequencies near \( \omega_c \). Therefore, at frequencies close to \( \omega_c \), all the right-handed \( L_a C_n \) series resonators can be approximately ignored as their impedances are much larger than those of the \( L_a C_n \) series resonators. As a result, at frequencies in stopband 1 (i.e., frequencies around \( \omega_b \)), the circuit in Fig. 4(a) can be approximated as the circuit shown in Fig. 4(b). It is seen that the circuit in Figure 4(b) is the same as that of the conventional BSF shown in Fig. 1. Therefore, all the element values in Fig. 4(b) can be determined by substituting the midband angular frequency \( \omega_0 \) and fractional bandwidth \( FBW_a \) of stopband 1 into (1) - (3).

Similarly, at frequencies in stopband 2 (i.e., frequencies around \( \omega_b \)), the circuit in Fig. 4(a) can be approximated as the circuit shown in Fig. 4(c), and all the element values in Fig. 4(c) can be determined by the specifications \((\omega_b, FBW_b, \text{etc})\) of stopband 2, using equations (1) - (3).

Therefore, the circuit in Figure 4(a) operates as a dual-band bandstop filter, and all of its element values can be decided by using (1)-(3). As we know, in the conventional BSF, the values of the \( J \)-inverters are assumed unvaried with frequency. In our design of the DBBBSF, we also assume that the \( J \)-inverters are unvaried over the dual stopbands. To end this purpose, we can determine \( C_{bi} \) \((i=1,2,\ldots,n)\) in Fig. 4(a) using the following relation:

\[ C_{bi} = \frac{\omega_a}{\omega_b} \cdot \frac{FBW_b}{FBW_a} C_{ai} \quad (i=1,2,\ldots,n) \]

where \( C_{ai} \) may take arbitrary values.

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\[ \begin{array}{c} L_a \\omega_a \\omega_c \\omega_0 \end{array} \]

\[ \begin{array}{c} L_a \\omega_a \\omega_c \\omega_0 \end{array} \]

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\[ \begin{array}{c} L_a \\omega_a \\omega_c \\omega_0 \end{array} \]
In the 2-degree Chebyshev DBBSF, we use four microstrip open stubs to realize the series resonators having $L_{ai}C_{ai}$ and $L_{bi}C_{bi}$ ($i=1, 2$). The J-inverters between the resonators as shown in Figure 4(a) are also realized by using microstrip quarter-wavelength lines whose characteristics admittances are calculated by using (2) and (3).

![Fig. 4](image)

III. A DESIGN EXAMPLE

A 2-degree Chebyshev DBBSF is designed by using microstrip lines to validate the design method proposed above. The central frequencies of the two stopbands are 1.7 and 2.3GHz, respectively. The equal-ripple fractional-bandwidths of both stopbands are 40%. The admittance inverters in Figure 4(a) are realized by using microstrip quarter-wavelength lines, while the LC series resonators are realized by using microstrip quarter-wavelength open stubs.

Figure 5(a) and 6(b) show a microstrip quarter-wavelength open stub and its equivalent LC series resonator, respectively. The microstrip open stub has a length $l_a$, a width $w_a$, a characteristic impedance $Z_a$, and is quarter-wavelength at $\omega_a$.

$$l_a = \frac{\pi c}{2 \omega_a \sqrt{\varepsilon_{\text{eff}}}}, \quad \omega_a = \frac{1}{\sqrt{L_a C_a}}$$

where $c$ is the speed of light in free space, $\varepsilon_{\text{eff}}$ is the effective dielectric constant of the stub.

Assume $X_{\text{in}}$ is the input reactance of the open stub, and $X_a$ of the $LC$ series resonator. Then by equating the reactance slope parameter of $X_{\text{in}}$ and $X_a$ at $\omega_a$, we get

$$Z_a = \frac{4 \omega_a L_a}{\pi}$$

By using (8) and (9), the lengths and widths of the quarter-wavelength lines and open stubs are determined easily.

![Fig. 5](image)

In the 2-degree Chebyshev DBBSF, we use four microstrip open stubs to realize the series resonators having $L_{ai}C_{ai}$ and $L_{bi}C_{bi}$ ($i=1, 2$). The J-inverters between the resonators as shown in Figure 4(a) are also realized by using microstrip quarter-wavelength lines whose characteristics admittances are calculated by using (2) and (3).

Fig. 6 shows the configuration and dimensions of the 2-degree microstrip DBBSF. A substrate with a dielectric constant of 9.8, a thickness of 1.27mm, and a loss tangent of 0.003 is used. The dimensions of the filter are obtained by using an electromagnetic simulator, Sonnet em.[7]

![Fig. 6](image)

Fig. 7 shows a comparison of the frequency responses of the 2-degree Chebyshev DBBSF. The solid lines are simulated results of the microstrip filter shown in Fig. 6 by using Sonnet em. Lossless substrate and conductors are assumed in the simulation. On the other hand, the broken lines are computed from the equivalent circuit shown in Figure 4(a). The agreement between the solid and broken lines is good at frequencies around the stopbands, and at frequencies in the passband between the dual stopbands.
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IV. CONCLUSION

A novel circuit of DBBSF using composite shunt resonators is proposed, and its design method is described. A 2-degree microstrip DBBSF with center frequencies of 1.7 and 2.3GHz is designed, fabricated, and tested. The measured frequency response agrees excellently with the theoretical prediction, and this validates well our proposed design method and filter structure.