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_{ri}, capacitor C_{ri}, and admittance-inverter $J_{i,i+1}$ are related by the following well-known formulas [5].

$$L_{r,i} = \frac{1}{\omega_0^2 C_{r,i}} \quad (i=1 \text{ to } n), \quad \Omega_c=1 \text{ (rad/sec)}, \qquad (1)$$

$$J_{01} = \sqrt{\frac{\omega_0 G_0 C_{r1}}{FBW \cdot \Omega_c g_0 g_1}}, \quad J_{n,n+1} = \sqrt{\frac{\omega_0 C_{r,n} G_{n+1}}{FBW \cdot \Omega_c g_n g_{n+1}}} \qquad (2)$$

$$J_{i,i+1} = \frac{\omega_0}{FBW \cdot \Omega_c} \sqrt{\frac{C_{r,i} C_{r,i+1}}{g_i g_{i+1}}} \quad (i=1 \text{ to } n\text{-}1) \qquad (3)$$

where ω_0 is the midband angular frequency of the BSF, *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.
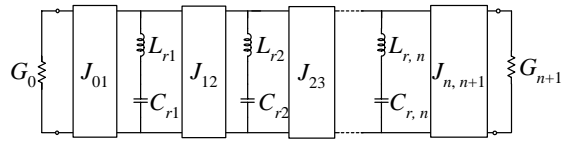

Fig. 1   Bandstop filter using series *LC* resonators and *J*-inverters.

Fig. 2(a) shows a composite shunt resonator [6]. It has two series *LC* resonators connected in parallel. It exhibits two anti-resonances at ω_a and ω_b, respectively, and a resonance at ω_0. Assume $\omega_a<\omega_b$, then at frequencies between ω_a and ω_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 ω_0. The equivalence equations between these two types of resonators are given below [6]:

$$L_r = \frac{2L_a{'}L_b{'}}{L_a{'}+L_b{'}} \quad , \quad C_r = \frac{1}{\omega_0{}^2 L_r}$$

(4)

$$L_a{'} = \frac{\left(1-\left(\omega_a\big/\omega_0\right)^2\right)^2}{1+\left(\omega_a\big/\omega_0\right)^2}L_a \quad , \quad L_b{'} = \frac{\left(1-\left(\omega_b\big/\omega_0\right)^2\right)^2}{1+\left(\omega_b\big/\omega_0\right)^2}L_b$$

(5)

$$\omega_a = \frac{1}{\sqrt{L_a C_a}} \quad , \quad \omega_b = \frac{1}{\sqrt{L_b C_b}} \quad , \quad \omega_0 = \frac{1}{\sqrt{(L_a+L_b)\frac{C_a C_b}{C_a+C_b}}}$$
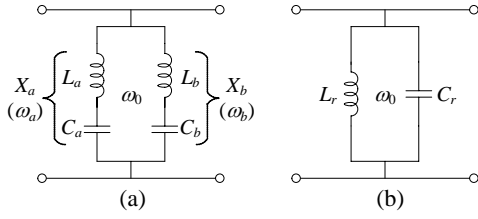
(6)

Fig. 2 (a) A composite shunt resonator having two series LC resonators, and (b) its equivalent shunt LC resonator at frequencies close to ω_0.
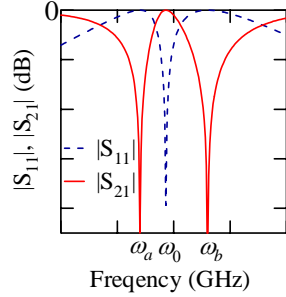

Fig. 3 Frequency response of a composite shunt resonator.

Fig. 3 shows a typical frequency response of the composite shunt resonator shown in Fig. 2(a). Two stopbands around ω_a and ω_b are observed, and they are caused by the resonances of the two LC series resonators. Meanwhile a passband is formed around ω_0.

As stated above, a composite shunt resonator exhibits dual stopbands around its 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 $L_{ai}C_{ai}$ ($i=1,2,…,n$) series resonators in Fig. 4(a) resonate at ω_a. Then a stopband (namely stopband

1) around ω_a is formed by these resonators. Similarly, let all the $L_{bi}C_{bi}$ ($i=1,2…,n$) series resonators resonate at ω_b, then stopband 2 around ω_b is formed. Therefore, the circuit in Figure 4(a) is a filter possessing dual stopbands.

Next, we describe design considerations of this DBBPF. Assume $\omega_a<\omega_b$. Since all the $L_{ai}C_{ai}$ series resonators (i.e., the left-handed series resonators of the composite resonators) in Fig. 4(a) resonate at ω_a, their impedances are close to zero at frequencies near ω_a. Therefore, at frequencies close to ω_a, all the right-handed $L_{bi}C_{bi}$ series resonators can be approximately ignored as their impedances are much larger then those of the $L_{ai}C_{ai}$ series resonators. As a result, at frequencies in stopband 1 (i.e., frequencies around ω_a), 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 ω_a and fractional bandwidth FBW_a of stopband 1 into (1) - (3).

Similarly, at frequencies in stopband 2 (i.e., frequencies around ω_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 (ω_b, FBW_b, 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 DBBSF, we also assume that the J-inverters are unvaried over the dual stopbands. To end this purpose, we can determine $C_{b,i}$ ($i=1,2…,n$) in Fig. 4(a) using the following relation:

$$C_{b,i} = \frac{\omega_a}{\omega_b} \cdot \frac{FBW_b}{FBW_a} C_{a,i} \quad (i=1,2…,n)$$

(7)

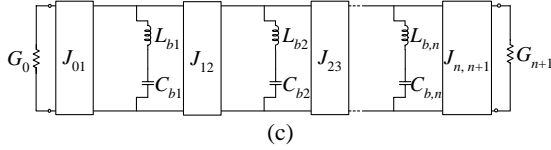where $C_{a,i}$ may take arbitrary values.

(a)

(b)

(c)
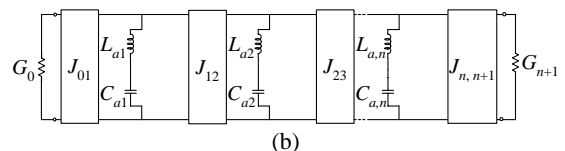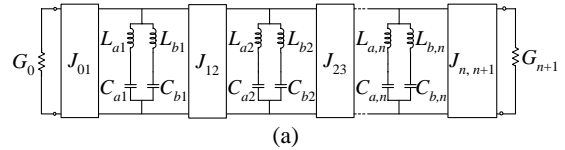
Fig. 4 (a) A novel dual-band bandstop filter (DBBSF), (b) Approximate circuit of the DBBSF at frequencies near ω_a, and (c) Approximate circuit of the DBBSF at frequencies near ω_b.

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 stop-bands 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 microtsrip 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 ω_a.

$$l_a = \frac{\pi c}{2\omega_a \sqrt{\varepsilon_{eff}}} \; , \; \omega_a = \frac{1}{\sqrt{L_a C_a}} \qquad (8)$$

where c is the speed of light in free space, ε_{eff} is the effective dielectric constant of the stub.

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

$$Z_a = \frac{4\omega_a L_a}{\pi} \qquad (9)$$

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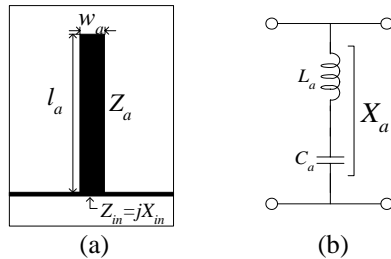

(a)   (b)

Fig.5 (a) A quarter-wavelength microstrip open stub, and (b) its equivalent series LC resonator.

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].
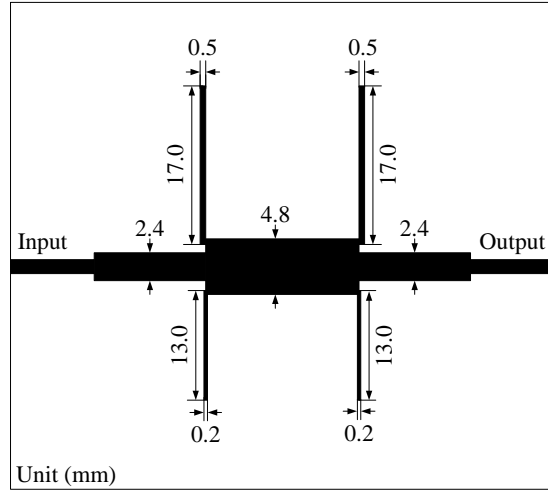

Fig. 6 Configuration and dimensions of the 2-degree microstrip DBBSF.

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.
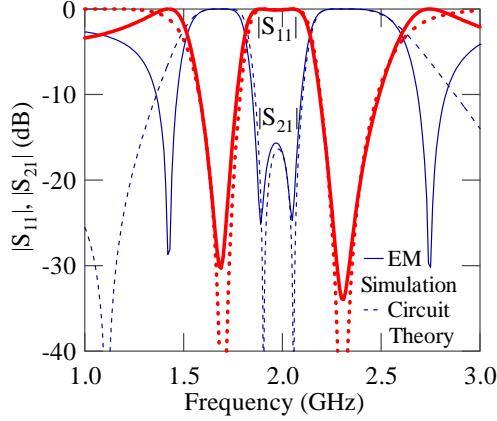
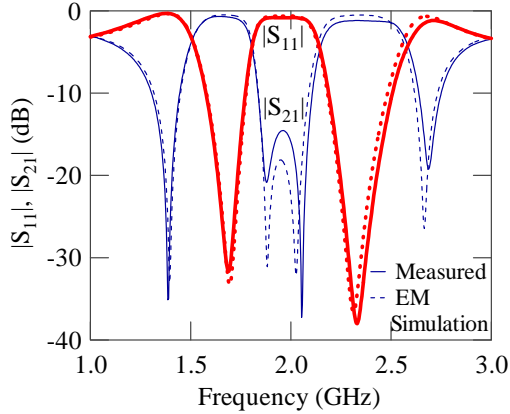Fig. 7 Comparison of the theoretical frequency responses of the 2-degree Chebyshev DBBSF.

Fig. 8 Comparison of the measured and simulated frequency responses of the 2-degree microstrip DBBSF.

The microstrip filter is fabricated and then measured using a network analyzer HP8510C. The measured data are drawn in Fig. 8 by solid lines, and are compared with the broken lines simulated by Sonnet em when taking into account of the dielectric and copper ($\sigma=58 \times 10^6$ S/m) losses. Over both the passband and stopbands, an excellent agreement is observed between the solid and broken lines.

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.

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