A Simple Method of Designing Dualband and Multi-Bandpass Filters

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Abstract. The theme of this paper is to present a simple technique to design dual-bandpass filters. This technique is based on the frequency transformations of prototype lowpass filter to the desired bandpass and band reject filters and arranging them in series and shunt configurations in a special way to meet the desired specifications. Different possible combinations are considered and presented the best possible configuration to validate this new design. Emphasis is given to dual bandpass filter while this can be extended to multi-bandpass filters as well. The design of dual bandpass with different orders is presented in this paper for maximally flat and equal ripple filters.

Keywords: Dual-bandpass filter, maximally-flat filter, equal-ripple filter, bandpass filter, Bandstop filter, frequency transformation.

1. Introduction

In recent times, the use of dual-bandpass filters has been increased significantly in communication systems and microwave systems. In a transceiver, the transmitting frequency and receiving frequency are separated by very small gap. Hence it is preferable to use a single dual-bandpass filter.

In the communication systems, with the advancement in technology, a single transceiver operating at multiple frequency bands are used and this leads to the designing of multi bandpass filters.

In the literature, different methods have been proposed to design dual and multi-bandpass filters [1], [2], [3], [4], [5]. A simple method of designing a dual-bandpass filter is to cascade the bandpass filter with a band reject filter [6], [7], [8], [9].

In this paper, a simple method is proposed to design a dual-bandpass filter and triple-bandpass filter in the X-band. This method suggests designing the dual-bandpass filter by designing the bandpass and bandstop branches individually and their interconnections in series and shunt orientations to get better result compared with the available methods in the literature [1], [2]. This method is analyzed with maximally flat and equal ripple filter for different orders [10], [11].

2. Problem formulation

The objective of this paper is to propose a simple method to design a dual bandpass filter. In order to design dual bandpass filter, initially, a bandpass filter and a bandstop filter are designed. These bandpass filter and bandstop filter are designed from a prototype lowpass filter with the help of frequency transformations [10], [11].

The dual-bandpass filter is designed in the X-band (8.0 GHz – 12.0 GHz). A third order lowpass filter shown in Figure 1 is used for converting into bandpass filter and bandstop filter [10]. Lowpass filter element values are given in Table 1.

The bandpass and bandstop filters can be obtained from lowpass prototype filter using Table 2. For a bandpass filter, the series inductance present in lowpass prototype filter is transformed to the series combination of inductor and capacitor and for bandstop filter, the series inductor is transformed to parallel combinations of inductor and capacitor.

Table 1: Third order lowpass filter element values

Type	g1	g2	g3
Maximally-flat	1	2	1
Equal-ripple	3.3487	0.7117	3.3487

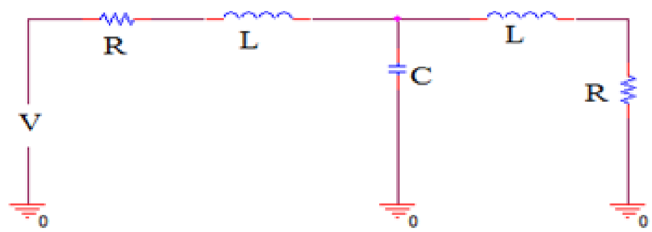
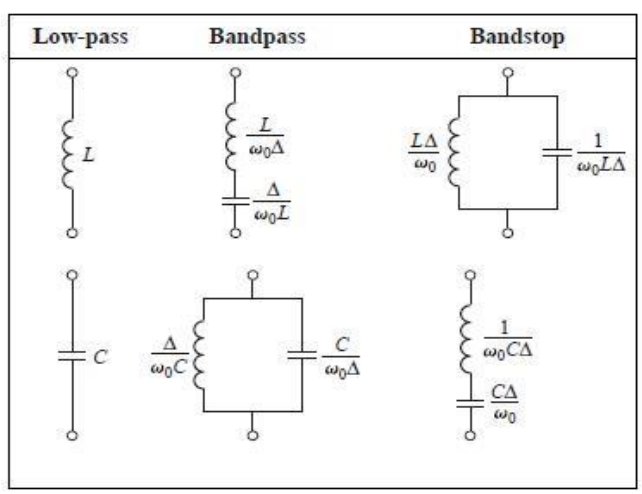


Fig. 1. Third order lowpass prototype filter.

Table 2: Conversions from lowpass prototype filter to bandpass filter and bandstop filter



Shunt capacitance present in lowpass prototype filter is transformed to the parallel combination of inductor and capacitor for bandpass filter. The shunt capacitance is transformed to a series connection of inductor and capacitor for bandstop filter.

Next step is to get the element values of a bandpass filter and bandstop filter from the element values of lowpass prototype filter.

The element values of the bandpass filter can be obtained using the following formulas.

For the series branch, element values are calculated using:

$$L_n = \frac{g1}{\Delta\omega_0} \tag{1}$$

$$C_n = \frac{\Delta}{g1\omega_0} \tag{2}$$

For the shunt branch element values are calculated using:

$$L_n = \frac{\Delta}{g2\omega_0} \tag{3}$$

$$C_n = \frac{g2}{\Delta\omega_0} \tag{4}$$

Similarly, for a bandstop filter, the element values for the series branch are calculated as:

$$L_n = \frac{\Delta g1}{\omega_0} \tag{5}$$

$$C_n = \frac{1}{g1\Delta\omega_0} \tag{6}$$

and for the shunt branch element values are calculated using:

$$L_n = \frac{1}{g2\Delta\omega_0} \tag{7}$$

$$C_n = \frac{\Delta g2}{\omega_0} \tag{8}$$

where Δ is the fractional bandwidth of the passband and ω_0 is the center frequency, defined as:

$$\Delta = \frac{\omega_2 - \omega_1}{\omega_0} \tag{9}$$

$$\omega_0 = \sqrt{\omega_1\omega_2} \tag{10}$$

The specifications of the bandpass and bandstop filter are represented in Table 3. The conventional bandpass filter is shown in Figure 2 and element values obtained from the formulas are given in Table 4 using frequency transformations.

The schematic of bandstop filter is shown in Figure 3 and the element values obtained from the formulas are given in Table 5 using frequency transformations.

The scattering parameters of bandpass and bandstop filters are obtained and are shown in Figure 4 and Figure 5, respectively.

Table 3: Specifications for designing X band filter using lumped elements

Type of filter	Frequency range	Center frequency	Fractional Bandwidth
Bandpass	8 GHz –12 GHz	9.79 GHz	0.4082
Bandstop	9.5GHz – 10.5GHz	9.98 GHz	0.1001

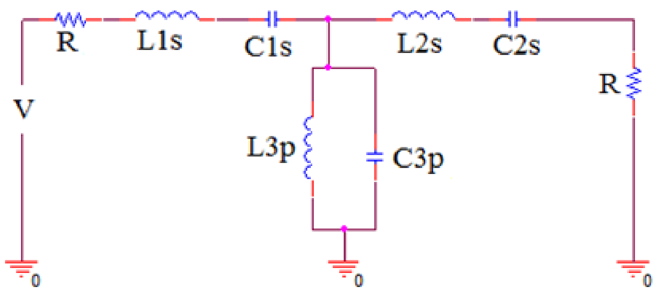


Fig. 2. Schematic of bandpass filter from third order lowpass prototype filter.

Table.4: Inductance and capacitance values for bandpass filter

Element	Equal-ripple	Maximally-flat
L1s, L2s (H)	13.324 n	3.9789 n
C1s, C2s (F)	0.16899 p	0.5658 p
L3p (H)	1.9878 n	0.70736 n
C3p (F)	1.1327 p	3.1831 p
R(Ω)	50	50

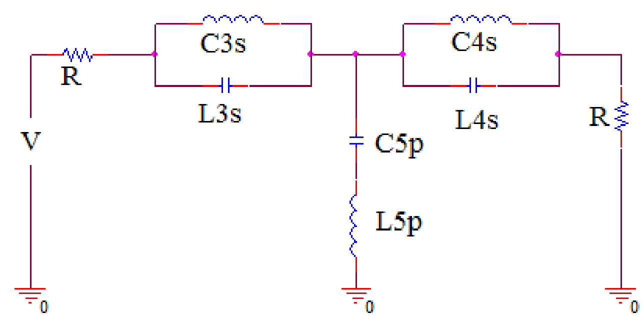


Fig. 3. Schemtic of bandstop filter from third order lowpass prototype filter.

Table 5: Inductance and capacitance values for bandstop filter

Element	Equal-ripple	Maximally-flat
L3s, L4s (H)	0.43543 n	0.13003 n
C3s, C4s (F)	4.7527 p	15.915 p
L5p (H)	55.907 n	0.19894 n
C5p (F)	0.037017 p	0.10402 p
R(Ω)	50	50

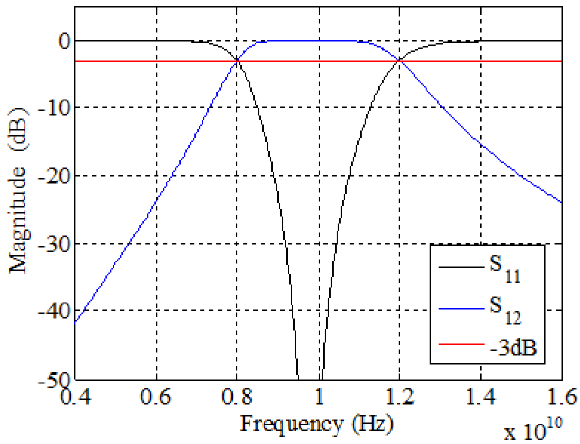


Fig. 4. Scattering parameters of a bandpass filter.

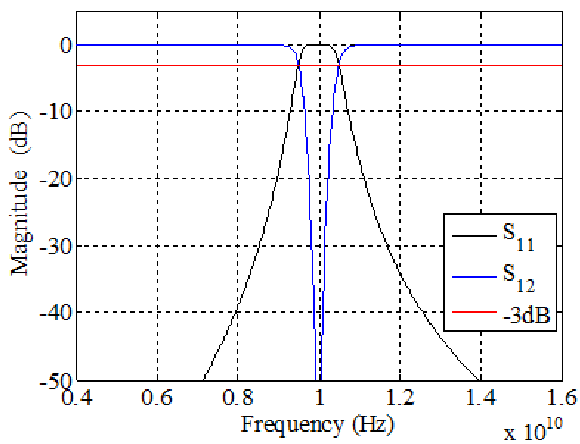


Fig.5. Scattering parameters of a bandstop filter.

3. Dual bandpass filter design

Dual bandpass filter can be designed using numerous methods [1], [2] with the help of bandpass filter and bandstop filter. There are three methods by which dual bandpass filter can be obtained.

1) The cascaded connection of bandpass and bandstop filters.
2) The parallel connection of bandpass and bandstop filters.
3) The series connection of bandpass and bandstop filters.

The very frequently used method is cascade connection of bandpass and bandstop filters. The same dualband operation can be obtained by parallel connection of bandpass and bandstop filters in branch wise. But it has the disadvantage of not meeting the specifications. Hence in this paper, the new proposed method is obtained by manipulating these cascade and parallel connections in hybrid form. This hybrid form is obtained by designing the individual series and shunt branch connection of bandpass filter and bandstop filters and then obtaining its final circuit diagram.

The traces shown in Figure 6 are in accordance with different design methods. From the graph, it is concluded that the series connection of bandpass and bandstop filters gives the better performance compared to other two designs (cascaded connection of bandpass and bandstop filters, parallel connection of bandpass and bandstop filters). Although the response corresponding to the cascade connection of bandpass and bandstop filters is reasonably good, it does not give that much flat response as given by series connection of bandpass and bandstop filters. The design shown in Figure 7 is the series connection of bandpass and bandstop filter.

After choosing the series connection of bandpass and bandstop filters for designing the dual bandpass filter, different order filters are designed. Results are compared for different order filter and are shown in Figure 8. From the simulation results it is concluded that as the order of the filter is increased, the response approaches to the ideal response.

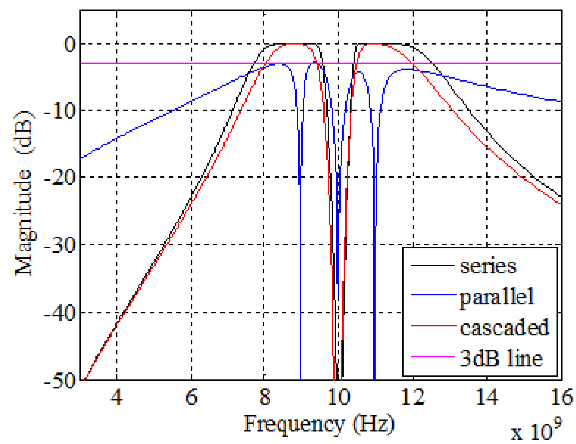


Fig.6. Comparison of three structures to designs dual bandpass filter.

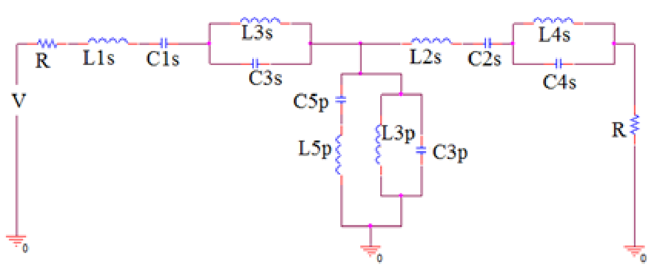


Fig. 7. Schematic of third order dual bandpass filter from bandpass bandstop filters.

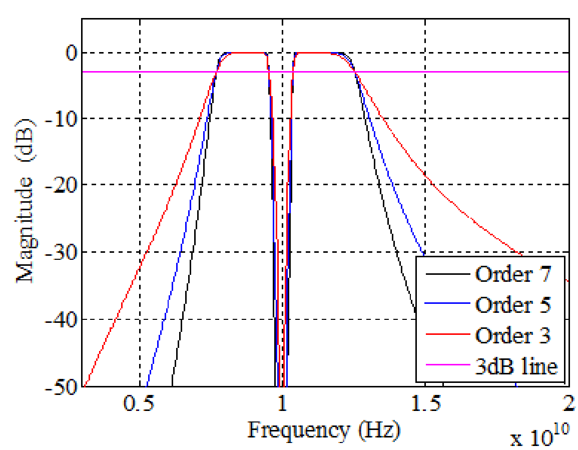


Fig. 8. Comparison of different order filters.

For the same design (series connection of bandpass and bandstop filters), third order dual bandpass filter results are compared by changing the fractional bandwidth (Δ) of bandstop filter while keeping the fractional bandwidth (Δ) of bandpass filter constant. Results are shown in Figure 9 and it is clear that, if the fractional bandwidth of bandstop filter is increased, the pass band is shifted accordingly but the roll-off remains same.

Figure 10 shows the response of third order maximally-flat dual bandpass filter. This filter is used where flat pass band gain is required but the roll-off is not of much importance. As it is a dual bandpass filter, it passes frequency ranging from 8.0 GHz – 9.5 GHz and 10.5 GHz – 12.0 GHz.

Figure 11 shows the response of third order equal-ripple dual bandpass filter. This filter is used where flat pass band gain is not required but the roll-off is of much importance.

The triple bandpass filter is designed for the frequency range 4.0 GHz – 12.0 GHz. To design the triple bandpass filter same dual pass filter with series connection of bandpass and bandstop filters. But one modification is made in the design that one more bandstop filter is added in series as shown in Figure 12. The element values for triple bandpass filter are given in Table 6. Result of triple band filter is shown in Figure 13.

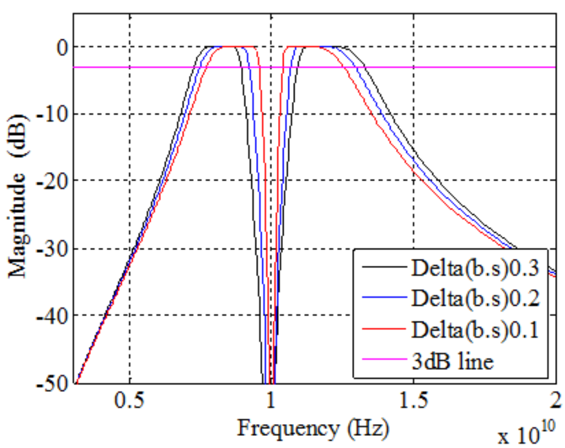


Fig. 9. Comparison of different bandstop fractional bandwidth (Δ).

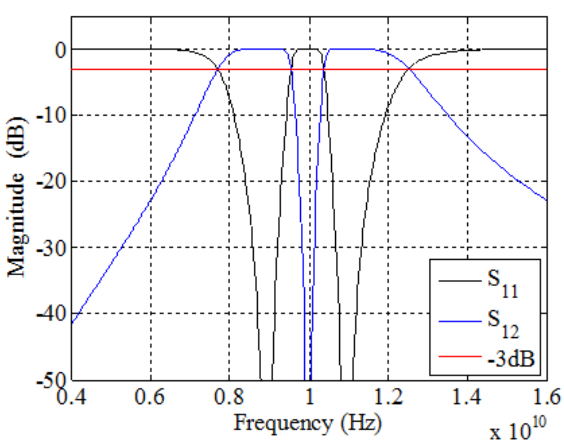


Fig. 10. Third order maximally-flat dual bandpass filter.

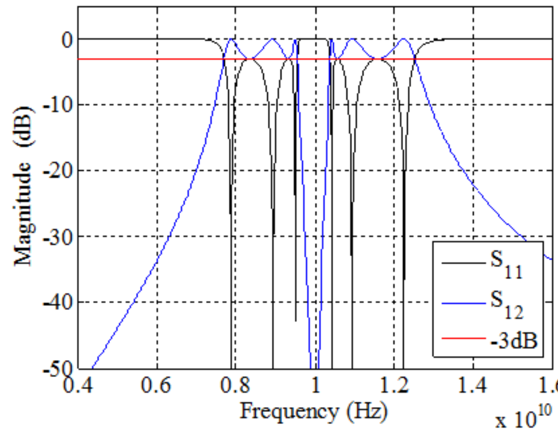


Fig. 11. Third order equal-ripple dual bandpass filter.

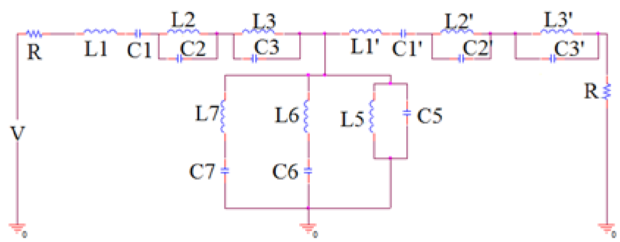


Fig. 12. Design of triple bandpass filter.

Table 6: Element values for triple bandpass filter.

Type	Series		Shunt	
Bandpass	L1, L1'	0.99472nH	L5	0.6631nH
	C1, C1'	0.53052pF	C5	0.79577pF
Bandstop-1	L2, L2'	0.22259nH	L6	3.9789nH
	C2, C2'	3.1831pF	C6	0.17808pF
Bandstop-2	L3, L3'	0.07977nH	L7	3.9789nH
	C3, C3'	3.1831pF	C7	0.06328pF

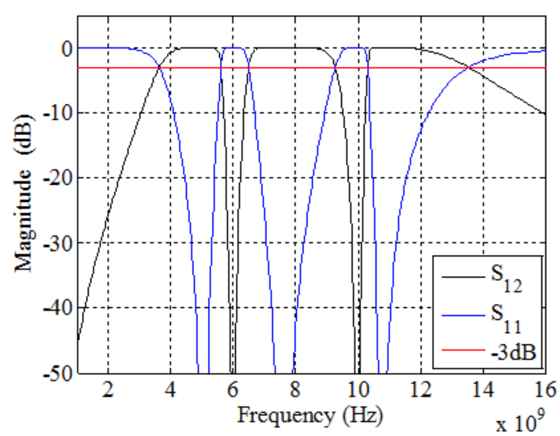


Fig. 13. Third order triple band bandpass filter.

4. Conclusion

To design dual bandpass filter, bandpass and bandstop filters are designed using lowpass prototype filter using filter transformations and filter scaling. It consists of combining individual bandpass and bandstop filters into one using different connections. Simulation results are compared and it is concluded that series connection of bandpass and bandstop filters gives more flat response.

Initially, different order filters are designed and the results are compared, it is concluded that as the order of the filter increases the response of the filter approaches to ideal filter. Third order dual bandpass filter is designed for maximally-flat filter (Butterworth filter) and equal-ripple filter (Chebyshev filter). After dual bandpass filter design triple bandpass filter is also analyzed. Although this is lumped design of dual/triple bandpass filter, it is possible to explore this technique for designing of multiband filter.

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