Synthesis of Symmetric and Asymmetric Triple-Stopband Microwave Filter using Frequency Transformation

Seema Awasthi [#1], Animesh Biswas [#2], Mohammed Jaleel Akhtar [#3]

[#1, 2, 3] *Department of Electrical Engineering, Indian Institute of Technology, Kanpur-208016, India*

[1] sema@iitk.ac.in; [2] abiswas@iitk.ac.in; [3] mjakhtar@iitk.ac.in

Abstract—**This paper presents the synthesis of direct coupled triple-stopband filters using coupling matrix approach. This design method is applicable to both symmetric and asymmetric triple stopband filter.The frequency transformation techniques has been applied for finding the locations of poles and zeros of a direct coupled triple stopband filter. By properly combining several single-band filtering functions, the multiband filtering function of various bandwidth are generated. Prescribed real or complex transmission zeros can also be employed in the triple-band filtering function. Finally 12-pole symmetric and asymmetric triple-stopband filters have been synthesised in cul-de-sac configuration to validate the proposed method.**

I. INTRODUCTION

In recent years, there has been growing interest in design of multiband filters because of their increasing use in modern wireless and satellite systems.The bandpass and bandstop filters play an important role to discriminate the desired and unwanted signal. The methods for deriving the coupling matrix of dual-bandpass filters have been extensively investigated by many researchers[6,8,9].But in case of multi-bandstop filters very few papers has been reported[2,4,7].There are different approaches to implement multiple bandpass filters among which frequency transformation is advantageous than others in terms of complexity for designing symmetric and asymmetric multiple-bandpass filters [1,3].

The dual bandstop filters are very attractive due to their ability to treat the unwanted double-sideband spectrum of high power amplifiers and mixers using one single filter to reduce the size and cost of the circuit[4,5].Other advantage of dual stopband is low passband insertion loss and group delay. Afterwards, Cameron et al.[4] has proposed the direct coupled dual stopband filter based on multiplexing method. He has applied the cul-de-sac synthesis technique to design dual stopband filter with direct coupled configuration, preventing degradation that is caused by the use of a transmission line between resonators. Cul-de-sac configuration for a bandstop filter is able to realize asymmetric characteristics without the need for negative or diagonal couplings and it provides a minimum couplings, minimal insertion loss and relatively high power handling [5].

So, the main purpose of this paper is to synthesis symmetric and asymmetric triple stopband filter based on coupling matrix approach using frequency transformation in cul-de-sac configuration.

II. DESIGN METHOD FOR TRIPLE STOP BAND FILTER

The design approach for a direct coupled single and dual stopband filter was discussed by Cameron [4,5] that is based on multiplexing method but here we applied similar direct coupled approach with using frequency transformation for designing symmetric and asymmetric triple stopband filters in cul-de-sac configuration.

A. Transfer funtion

A Bandstop filter's transfer function S11 and S21 may be expressed as ratios of two polynomials [4].

$$S_{21}(s) = \frac{F_N(s)}{\varepsilon_R E_N(s)},\ S_{11}(s) = \frac{P_N(s)}{\varepsilon E_N(s)} \qquad (1)$$

Where $s=j\omega$ and ω is the real frequency variable. For a Chebyshev filtering function, ε is a constant normalizing S_{21} to the equiripple level at $s=\pm j$ as follows:

$$\varepsilon = \frac{1}{\sqrt{10^{\frac{RL}{10}}-1}} \left.\frac{P_N(s)}{E_N(s)}\right|_{n=j} \qquad (2)$$

Where RL is the prescribed return loss level in dB and it is assumed that all the polynomials have been normalized such that their highest degree coefficients are unity. Once $P_N(s)$ and $F_N(s)$ are defined, the unitary condition of S parameters require that

$$E_N(s)E_N^*(-s) = P_N(s)P_N^*(-s) + F_N(s)F_N^*(-s) \qquad (3)$$

The poles can be obtained by evaluating the roots of the above expression and by selecting those with negative real part. Again, here $E_N(s)$ is generated from the poles by imposing equal to 1 the highest degree coefficient. The poles and zeros of the final multiple bands filtering function can be generated using the following frequency transformations [3]. Fig. 1 shows the frequency response of the symmetrical filter in three different frequency domains as discussed in [3].

B. Frequency Transformation for Symmetrical Filter

For the outer bands

$$s=\left(\frac{s'}{c_1}+\frac{c_1'}{s'}\right) \quad for \quad \Omega' > \Omega_0',$$
$$s=-\left(\frac{s'}{c_1}+\frac{c_1'}{s'}\right) \quad for \quad \Omega' < -\Omega_0' \tag{4}$$

For the inner band

$$s=\left(\frac{s'}{c_0}\right) for \quad -P_0<\Omega'<P_0 \quad . \quad \text{where } s = j\Omega \text{ and } s' = j\Omega' \tag{5}$$

For outer bands 1 and –1 in the Ω-domain are transformed to p_1 and Ω_1' in the Ω′–domain for Ω′> Ω_{12}', respectively, and 1 and –1 in the Ω-domain are transformed to -p_1 and -Ω_1' in the Ω′–domain for Ω′<- Ω_{12}'.Using the transformations, c_1, c_2, c_0 edge frequencies of the filter in the Ω′ -domain are given as:

For outer bands:

$$c_1 = p_1-\Omega_1',\ c_1' = \frac{p_1\Omega_1'}{p_1-\Omega_1'},$$

for central band $\quad c_0 = p_0 \quad$ (6)

The transformation used for Ω′–domain to ω-domain for the outer bands are given as:

$$s=\left(\frac{s'}{d_1}+\frac{d_1'}{s'}\right) \quad d_1=\frac{\omega_{11'}-\omega_{11}}{p_1}, \quad d_1'=\frac{\omega_{11'}\omega_{11}}{\omega_{11'}-\omega_{11}}p_1 \tag{7}$$

and for central passband $\quad s=\frac{s'}{d_0} \quad$ (8)

Once the transformations are completed in all the bands, one evaluates the poles and zeros of the filtering function after each transformation. The unified filtering function is created by combining all the transformed poles and zeros.

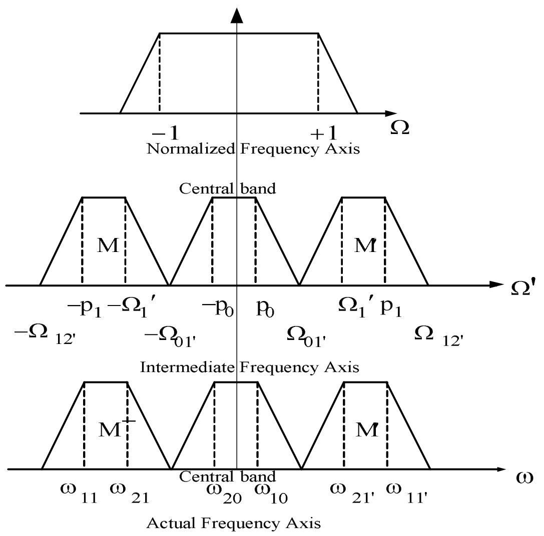

Fig. 1 Frequency response of the symmetrical filter in three different frequency domains, Ω is the normalized frequency for a single-passband low-pass prototype and Ω' is the normalized frequency for a triple-passband filter. The ω domain is the actual frequency domain where the filter operates [3].

C. Frequency Transformation for Asymmetrical Filter

In this design procedure we have followed the similar approach used for symmetrical triple stopband filter. Fig.2 shows the frequency response in Ω' domain [3].where c_1, c_2, c_3, c_4 are determined by the band edge frequencies in the Ω' domain by using (9-13).

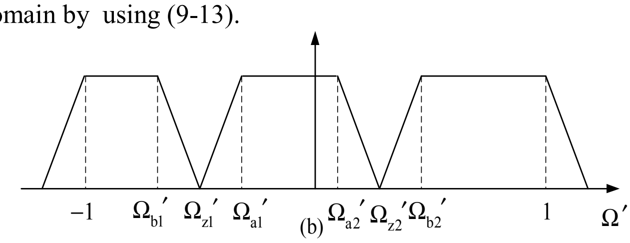

Fig. 2 Frequency response of the Asymmetrical filter in Ω' frequency domains.

$$S=\frac{S'}{c_1}+\frac{c_2}{S'-j\Omega_{z0}'} \qquad for \quad \Omega'>\Omega_{z0}' \tag{9}$$

$$c_2=\frac{(1+\Omega_{b2}')(1-\Omega_{z0}')(\Omega_{b2}'-\Omega_{z0}')}{(1-\Omega_{z0}'-\Omega_{b2}'^2+\Omega_{b2}'\Omega_{z0}')}, \quad c_1=\frac{(1-\Omega_{z0}')}{(1-\Omega_{z0}'+c_2)} \tag{10}$$

$$S=-\left(\frac{S'}{c_3}+\frac{c_4}{s'-j\Omega_{z0}'}\right) \quad for \quad \Omega'<\Omega_{z0}' \tag{11}$$

$$c_4=\frac{(1-\Omega_{b1}')(1+\Omega_{z0}')(\Omega_{b1}'-\Omega_{z0}')}{(1+\Omega_{z0}'-\Omega_{b1}'^2+\Omega_{b2}'\Omega_{z0}')}, \quad c_3=\frac{(1+\Omega_{z0}')}{(-1-\Omega_{z0}'+c_4)} \tag{12}$$

$$S=\frac{S'-j\Omega_{z0}'}{c_5} \qquad for \quad \Omega'>\Omega_{z0}' \qquad c_5=\frac{(\Omega_{a1}'+\Omega_{a2}')}{2} \tag{13}$$

III. FILTER SYNTHESIS

Here 12-pole symmetric and asymmetric triple-stopband filters have been synthesized here.

A. *Asymmetric 12-pole triple-band Filter*

To design a 12-pole asymmetric triple bandstop filter, a 4-pole low pass prototype for single band having transmission zeros at s=± 3j with return loss (RL) 20 dB has been chosen.in Fig. 2 for p_1=1, p_0= 0.20 and, Ωz0=0.1 Ω_{b1}=-0.5, Ω_{b2}=0.8, Ω_{a1}=0.05, Ω_{a2}=0.25,the unknown coefficients are calculated using (9-11), c_1= 0.2125, c_2= 3.3353 and c_3 = -0.4706, c_4 =-1.2375, c_5 =0.15.Using the frequency transformation given in [3],we can find the poles and zeros of the asymmetric triple bandstop filter in the Ω' domain as shown below. From the poles and zeros of the unified filtering function, the coefficients of the polynomials (Pn, En, Fn) are calculated and given below.

Poles=[-0.9772, -0.8186, -0.61520,-0.5032,0.9939 , 0.9396, 0.8590, 0.8063, 0.24920.1598,-0.0452, 0.0312].

Zeros= [1.2525, 0.6503, -0.1504, -2.28, 0.4800, -0.3500, -0.25, 0.55, 1.50].

En=1.0000, 1.1373 - 1.0796i, 2.8670 - 1.3971i , 2.0562 - 3.3249i , 2.3697 - 2.8471i , 0.9138 - 3.1336i , 0.5566 - 1.7193i, 0.0408 - 1.0474i , 0.0002 - 0.3488i , -0.0161 - 0.1147i, -0.0073 - 0.0191i , -0.0008 - 0.0021i, - 0.0001i].

Fn=[1.0000i 1.0796 , 2.2203i , 2.4341 , 1.6905i , 1.8840 , 0.5078i, 0.5791, 0.0393i , 0.0571, - 0.0055i, 0.0002, - 0.0000i].

Pn=[1 , -1.4024j, 4.1069 -8.6864j , -3.4266i , -1.7360j , 0.9835i, -0.1456, 0.0681i , -0.0097].

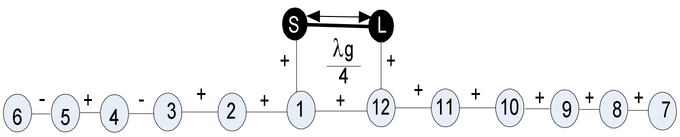

Fig.3 Coupling and routing diagram of 12-pole asymmetric triple bandpass filter

The topology of the asymmetric triple-band filter is shown in Fig. 3. The frequency response of the 12-pole stopband filter and its group delay is shown in Fig.4 and Fig. 5. The corresponding non zero elements of coupling matrix of the filter is given below.

M_{S1}= M_{1S}=1.0665, M_{12}= M_{21}=0.7514, M_{23}= M_{32}=0.5123, M_{34}= M_{43}=-0.3507,M_{45}= M_{54}=0.5350, M_{56}= M_{65}=-0.2697, M_{78}= M_{87}=0.2925, M_{89}= M_{98}=0.3833,M_{910}= M_{109}=0.5004, M_{1011}= M_{1110}=0.6397, M_{1112}= M_{1211}=0.7355, M_{12L}= M_{L12}=1.0664, M_{11}=0.1488, M_{22}=-0.0593, M_{33}=-0.2383, M_{44}=-0.0602, M_{55}=-0.5100, M_{66}=0.0148, M_{77}= -0.4342, M_{88}= -0.3874, M_{99}=0.1814, M_{1010}= 0.1520, M_{1111}= -0.0631, M_{1212}= 0.1489

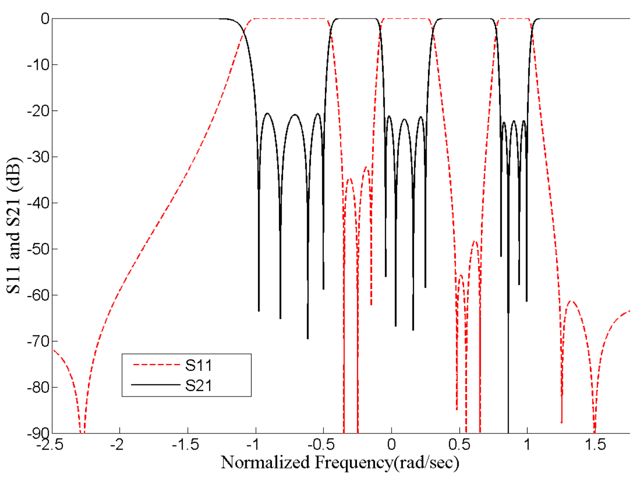

Fig.4 The frequency response of 12-pole asymmetric triple bandstop filters from the coupling matrix.

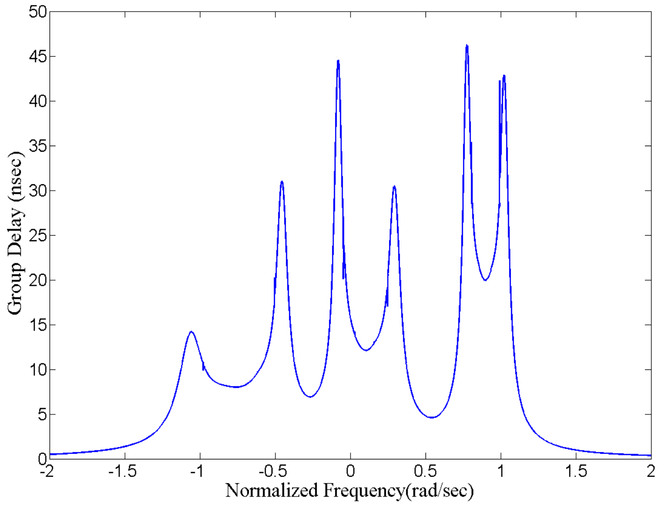

Fig.5 Group Delay of 12-pole asymmetric triple bandstop filters.

B. *Symmetric 12-pole Triple-band Filter*

To design a 12-pole symmetric triple bandstop filter, a 4-pole low pass prototype for single band having transmission zeros at s=± 3j with return loss (RL) 20 dB has been chosen. In Fig. 1 for p_1=1, p_0= 0.20 and the unknown coefficients are calculated using (6), c_1= 0.40, c_1'= 1.5 and c_0 =0.2.Similarly, the coefficients of the polynomials (Pn, En, Fn) are calculated and given below.

Poles= [±0.9834i, ±0.8600i, ±0.6976i, ±0.6101i, ±0.1867i, ±0.0812i]
Zeros= [±1.5543i, ±0.49435i, ±0.3890i, ±0.3890i]
En=[1.0000,1.3014, .4538,3.1951,4.0607,.6608 ,2.0003,0.9086,0.4114,0.1214,0.0286,0.0043,0.0005].
Fn= [1.0000i, 0, 2.6070i,0, 2.4688i,0, 1.0220i, 0, 0.1684i, 0 0.0056i, 0, 2.97e-5i].
Pn= [1.0i, 0, 2.9629i, 0, 1.4184i, 0, 0.2396i, 0, 0.0135i].

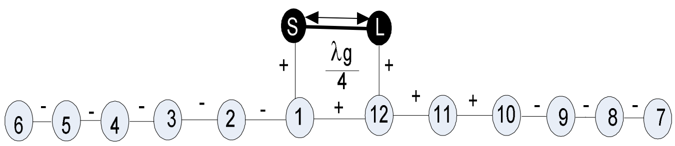

Fig.6 Coupling and routing diagram of 12-pole symmetric triple bandpass filter

The topology of the filter is shown in Fig. 6. The frequency response of the 12-pole stopband filter and its group delay is shown in Fig.7 and Fig. 8.The corresponding non-zero elements of coupling matrix of the filter are shown below.

M_{S1}= M_{1S}= M_{12L}= M_{L12}=1.1408, M_{12}= M_{21}= 0.7585, M_{1112}= M_{1211}=- M_{12}, M_{23}= M_{32}=-0.5761, M_{1011}= M_{1110}=-M_{32}, M_{34}= M_{43}= M_{910}= M_{109}=-0.4366,M_{45}= M_{54}= M_{89}= M_{98}=--0.5003, M_{56}= M_{65}= M_{78}= M_{87}=-0.2416, M_{22}=-0.0457, M_{33}=0.2408, M_{44}=0.2390, M_{55}=0.0109, M_{66}=-0.3164, M_{77}= -M_{66}, M_{88}= -M_{55}, M_{99}= -M_{44}, M_{1010}= -M_{33}, M_{1111}= - M_{22}.

IV. Conclusion

Synthesis of symmetrical and asymmetric triple stopband filters is presented in this paper. The coupling matrix is derived from the poles and zeros of the tri-band filtering function. Two filters having different number of passband have been synthesized using the coupling matrix in order to validate the present approach of the synthesis method. These filters are simple and compact in the Construction, flexible layout, and easy in tuning for the manufacturing on the production line. They become more important in the design of telecommunication and broadcast systems to prevent interference with other users.

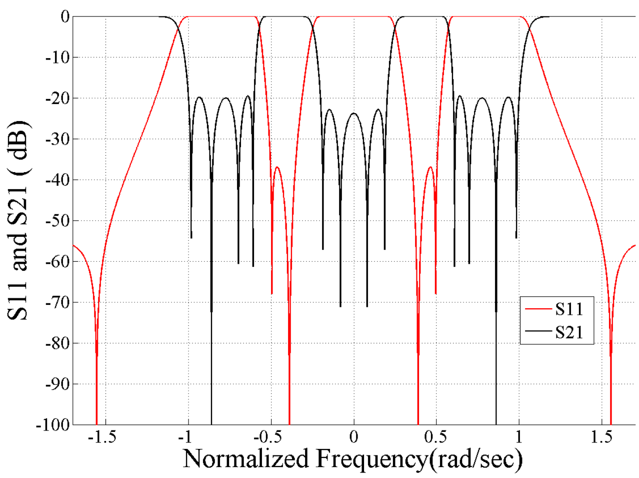

Fig.7 The frequency response of 12-pole symmetric triple bandstop filters from the coupling matrix.

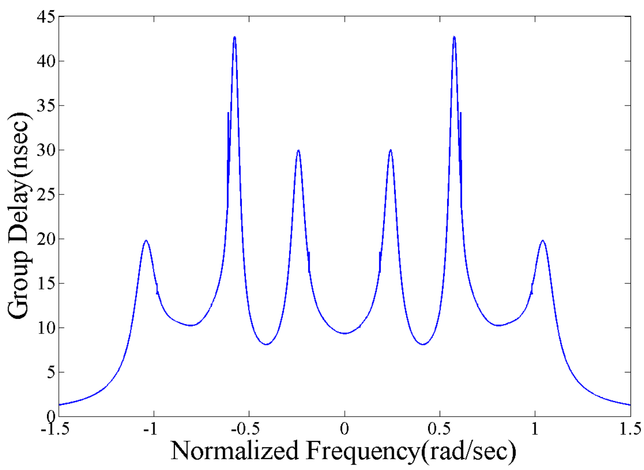

Fig.8 Group Delay of 12-pole symmetric triple bandstop filters.

References

[1] G. Macchiarella, S. Tamiazzo, "A design technique for symmetric dualband filters," *IEEE MTTS Int. Microw. Symp*, pp. 115–118, Jun. 2005.

[2] S. Amari and U. Rosenburg,"Direct Synthesis of a New Class of Bandstop Filters," *IEEE Trans. Microw. Theory Tech.*,vol. 52, no. 2, pp. 607–616, Feb. 2004.

[3] J. Lee and K. Sarabandi, "Design of triple-passband microwave filters using frequency transformations", *IEEE Trans. Microw. Theory Tech.*, vol.56, no.1, pp. 187–193, Jan. 2008.

[4] R. J. Cameron, M. Yu, and Y.Wang, "Direct-coupled microwave filters with single and dual stopbands," *IEEE Trans. Microw. Theory Tech.*, vol. 53, no. 11, pp. 3288–3297, Nov. 2005.

[5] R. J. Cameron, C. M.Kudsia, and R. R. Mansour, *Microwave Filters for Communication Systems*: Fundamentals, Design, and Applications, Hoboken, NJ: Wiley, 2007.

[6] Marjan Mokhtaari, Jens Bornemann, K. Rambabu, and Smain Amari, " Coupling-Matrix Design of Dual and Triple Passband Filters," *IEEE Trans. Microw. Theory Tech.*, vol.54, no.11, pp. 3940–3946, Nov. 2006.

[7] S. H. Han, X. L. Wang, and Y Fan., "Analysis And Design Of Multiple-Band Bandstop Filters," *Progress In Electromagnetics Research, PIER 70, 297–306, 2007.*

[8] Y. T. Kuo, J. C. Lu, C. K. Liao, and C. Y. Chang, "New Multiband Coupling Matrix Synthesis Technique and Its Microstrip Implementation," *IEEE Trans. Microw. Theory Tech.*, vol.58, no.7, pp. 1840–1850, Jul. 2010.

[9] X. Shang Y. Wang G.L. Nicholson M.J. Lancaster, "Design of multiple-passband filters using coupling matrix optimization," *IET Microw. Antennas Propag.*, Vol. 6, no. 1, pp. 24–30, Jan. 2012.