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ARC COUPLED BAND – PASS FILTERS

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Abstract: *A filter design of coupled band – pass filters is very often used in practise because exhibit smaller spread of filter elements then filter ladder configurations. In comparison to cascade synthesis method enable this type of filters to reach smaller filter element sensitivity. However in area of active filter design there are problems with active filter elements (active inductances or FDNR elements) which require relatively high quality factors and consequently relatively high numbers of active elements (OAs) too. In paper are prescribed some class of coupled band – pass filters using lossy active elements with minimised number of active elements (OAs). The possibilities of application and using of developed active band – pass filters are discussed in further details and explained in some examples.*

Key words: *Active, filter, design, coupled, band – pass, sensitivity, element spread, active inductance, FDNR element, optimization*

INTRODUCTION

The classically designed band - pass filter of the ladder structure exhibit very great inconvenient spread of element value namely by narrow band - pass filter types. Therefore as more practical filters for these applications are the capacitive (or inductive) coupled filter structures. The coupled band - pass topologies with relatively low sensitivity and concurrently small spread of filter element values are very suitable not only for direct realization of passive filters with lumped and distributed elements but also as RLC prototypes which are used as base of active filter realizations.

In this paper are prescribed some class of coupled band – pass filters using lossy active elements with minimised number of active elements (OAs). The possibilities of application and using of developed active band – pass filters are discussed in further details and explain in some examples.

1 THE BAND – PASS FILTER PROTOTYPES

The filter design of coupled filters is relatively easy and may be derived from standard filter design process. Although the coupled band – pass filters exhibit very good parameters (relatively low sensitivity and small spread of filter element values), filter design of coupled filters is not usual in nowadays expert literature published. The base of the design process is usual normalized low – pass RLC ladder filter prototype with normalized parameters (see Fig.1a).

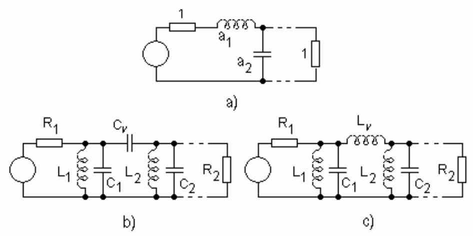


Fig.1: a) LP filter prototype, b) capacitive coupled , c) inductive coupled BP filter

Usually input required parameters are resonant frequency f_0, band-width B and impedance level defined by value of resistors R. If a_1 to a_i and b_1 to b_i are normalized parameters of selected approximation filter type (most often Bessel, Butterworth or Chebyshev), then resulting parameters of capacitive coupled band – pass filter (see Fig.1b) can be expressed as:

$$C_V = 1/2\pi f_0 R \quad (1) \quad , \quad L_i = BR/(2\pi f_0^2 a_i) \quad (2)$$

$$C_1 = 1/(4\pi^2 f_0^2 L_1) - C_V \quad , \quad (3)$$

$$C_2 = 1/(4\pi^2 f_0^2 L_2) - 2C_V \, , \quad (4)$$

$$C_{n-1} = 1/(4\pi^2 f_0^2 L_{n-1}) - 2C_V \, , \quad (5)$$

$$C_n = 1/(4\pi^2 f_0^2 L_n) - C_V \; . \quad (6)$$

In a case of inductive coupled band – pass filter (see Fig.1b) then resulting parameters can be derived as:

$$L_V = R/2\pi f_0 \quad (7), \qquad C_i = a_i/(2\pi BR) \quad , \qquad (8)$$

$$L_{ip} = BR/(2\pi f_0^2 a_i) \qquad (9)$$

$$1/L_1 = 1/L_{1p} - 1/L_V \, , \qquad (10)$$

$$1/L_2 = 1/L_{2p} - 1/2L_V \, , \qquad (11)$$

$$1/L_{n-1} = 1/L_{(n-1)p} - 1/2L_V \, , \qquad (12)$$

$$1/L_n = 1/L_{np} - 1/L_V \, . \qquad (13)$$

As an example of coupled band – pass filter a filter with following parameters was designed: Butterworth band – pass filter of 4th order , resonant frequency f_0=3 kHz, band-width B =300 Hz, R=1 kΩ. Resulting filter circuit diagrams with filter parameters we can see from Fig.2. How is very good seen, in comparison to standard LC ladder band – pass filter (Fig.2a) with great inconvenient spread of value parameters (approx. 798), the coupled band – pass filter topology exhibit much smaller spread (max. approx. 27) value of filter parameters.

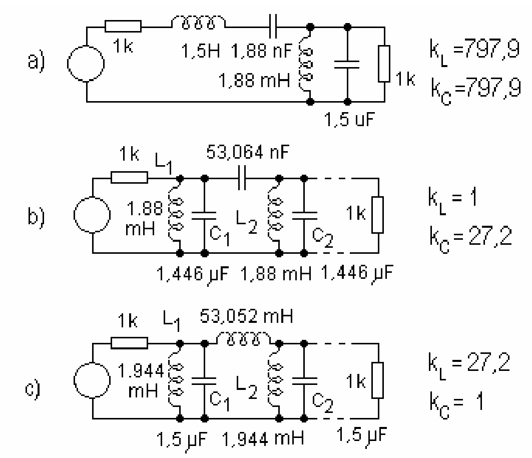


Fig.2: Resulting circuit diagrams :
a) standard LC ladder ,b) capacitive coupled, c) inductive coupled filters

2 THE ACTIVE REALIZATIONS OF COUPLED BAND – PASS FILTERS

The above mentioned coupled band – pass topologies can be directly as filter prototypes to active filter realizations used. In the filter from Fig.2b it is possible directly replace coils by active blocks simulated grounded inductors. There are many networks which can be successfully used.

The topology from Fig.2b can be transformed using Bruton´s transformation and then requirement of grounded FDNR blocks can be solved also relatively easy. In the both cases most often there are used for each inductor (or FDNR element) active blocks with two or more active elements (operational amplifiers OA) because enable to reach higher value of quality factor Q. In practise are very often used in active blocks GICs networks like Antoniu circuit (Fig.3) [4]. This circuit can be used for both cases – the modifications enable to realize active inductors as well as FDNR elements due to proper circuit modification, where only the character of load and responsible gates are selected -how it is shown in Fig.3.

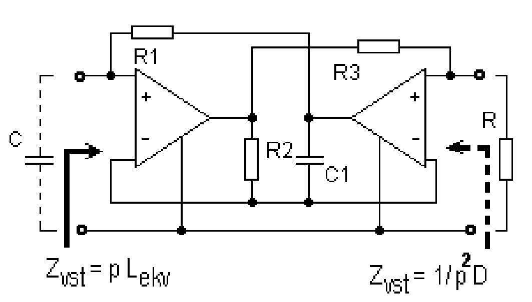


Fig.3: The example of active block - Antoniu GIC

3 THE COUPLED BAND - PASS FILTERS WITH LOSSY ACTIVE BLOCKS

There are some cases, where the coupled band – pass filters can be optimized and lossy active elements with smaller number of OAs can be realized. As an example we shall to optimize filters from Fig.2b and Fig.2c.

In the capacitive coupled network from Fig.2b we can suppose the resistors as lossy of the coils and to realize corresponding lossy active inductors of required parameters. Similarly in the inductive coupled networks from Fig.2c, after Bruton´s network transformation, can be the resistors supposed as lossy of the active FDNR blocks. Consequently in both cases can be design optimized and easy active lossy inductors – see Fig.4a and easy lossy FDNR blocks-see Fig.4b, with smaller number of OAs, can be used.

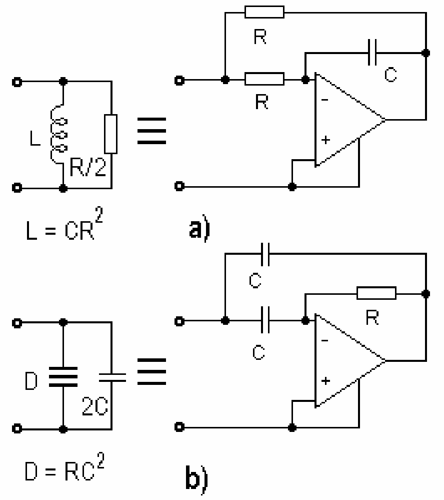


Fig.4: Lossy active blocks: a) inductor, b) FDNR circuit

Using above mentioned active lossy elements were both coupled band – pass filter modifications designed. Resulting circuits diagrams of active filters based on declared coupled filter prototypes are drawn in Fig.5 and Fig.6. To comparison transfer functions and sensitivity

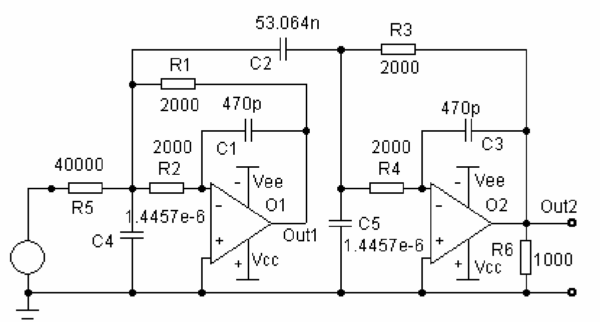


Fig.5: The resulting band-pass filter with active lossy inductors

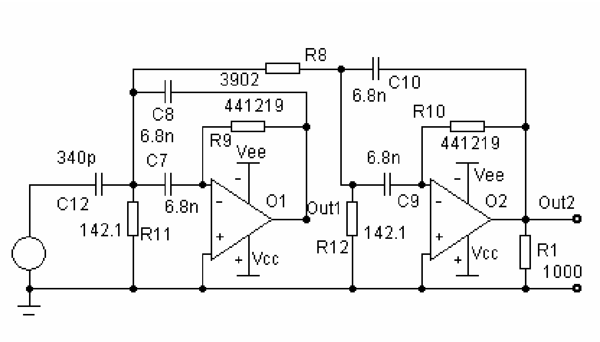


Fig.6: The resulting band-pass filter with active lossy FDNR blocks

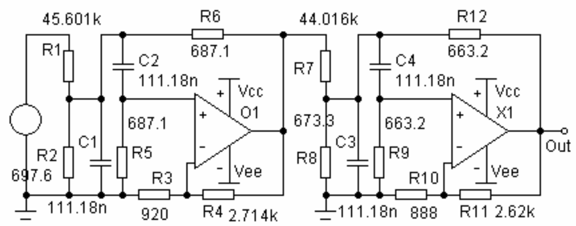


Fig.7: The resulting band-pass filter-cascade synthesis method - Salen-Key blocks

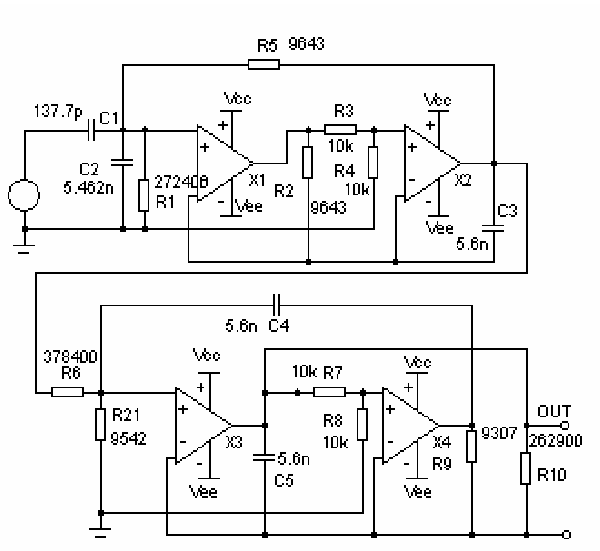
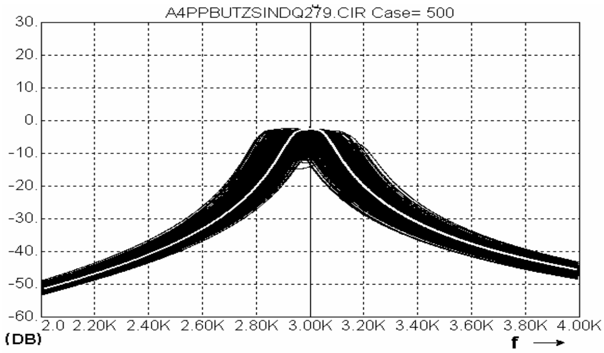
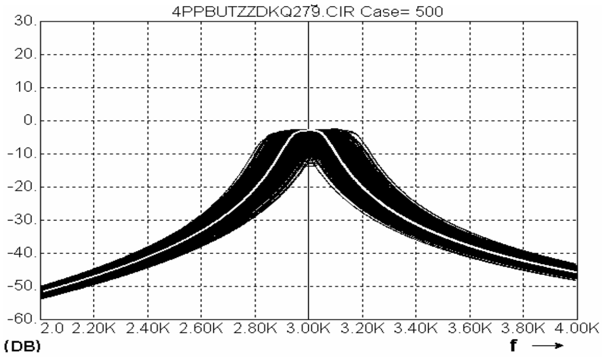


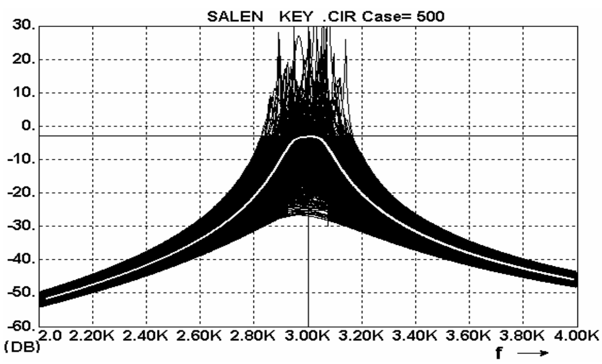
Fig.8: The resulting band-pass -cascade synthesis method - GIC blocks (NAF)



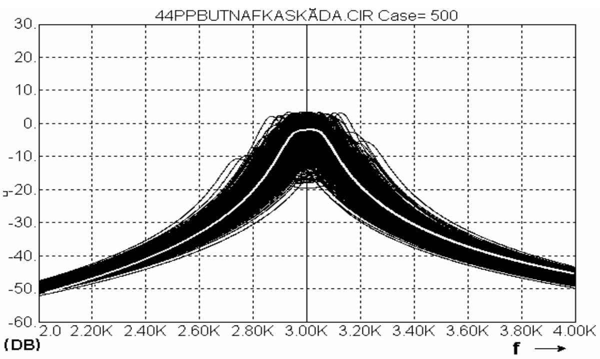
a)



b)



c)



d)

Fig.9: The Monte Carlo sensitivity analysis of magnitude responses: a) filter Fig.5, b) filter Fig.6, c) filter Fig.7, d) filter Fig.8.

analysis also two further modifications of band – pass filters of required parameters according standard cascade synthesis method were designed. In the Fig.7 is resulting circuit diagram of the filter designed with two Salen-Key blocks which have been designed using built -in filter designer from program MC7. Fig.8 present resulting circuit diagram obtained using NAF program [4]. The results of Monte Carlo (Gauss distribution) sensitivity analysis presents Fig.9. How we can see, the best results from point of sensitivity view exhibit optimized circuits based on coupled band – pass circuits. Worst case of sensitivity exhibit band – pass filter designed as cascade of active blocks (Salen – Key) with one OA , which is evidently far from optimized designed.

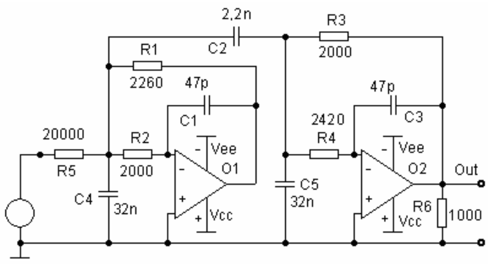


Fig 9.: The resulting band-pass filter with active lossy inductors (f_0=57 kHz)

As second example of active band – pass filter with lossy inductors has been designed and optimized active filter with required centre frequency 57 kHz, band width about 7 kHz. Resulting magnitude response, which is very close to theoretically designed band – pass filter curve is clear from graph drawn in Fig. 10.

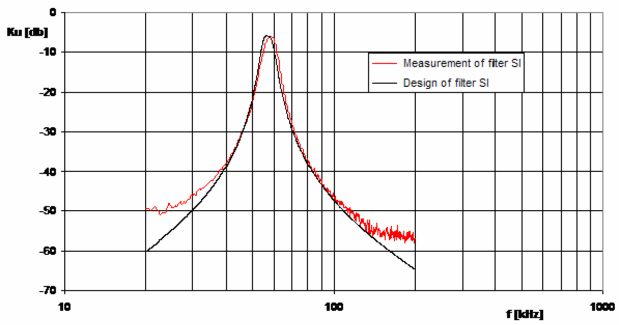


Fig.10: The resulting magnitude response of active band – pass filter from Fig. 9

By resulting active band – pass filters also investigations of real parameters of active elements (operational amplifiers) have been widely made. As most important parameter which is responsible for most significant deviations from required transfer response was found GBW parameter of OAs. By filter design must be active elements (OA) with sufficient value of GBW chosen, if not, then real transfer response will be in comparison to requirements shifted to lower frequency.

4 Conclusion

This paper deals with optimization of ARC band – pass filters based on lossy LC ladder prototypes. The prescribed synthesis method using capacitive or inductive coupled lossy band – pass filters enables minimization of element value spread, optimization of element sensitivities , minimization of number of active elements as well as increasing of dynamic range of whole filter. To easy filter synthesis process and possibility of optimization the short program has been developed. This program enable very quickly to optimize ARC coupled band – pass filter of 4^{th} and 6^{th} order of designed filter.

Using a new modern active elements (operational amplifier with wide GBW) the prescribed method enable to design of ARC coupled band – pass filters for frequencies about hundred kHz.

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