Filtering structures in pure current mode

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Abstract: - Analog circuits used as an interface between analog world and a digital core of electronic structures are required to operate under more and more strict conditions, mainly as the supply voltage and frequency range is concerned. New circuit techniques are being sought. The networks working in the pure current mode seem to be one of the possible solutions of that problem. Within the paper the idea of pure current mode is expanded, basic elements for the design of the network structures are proposed and examples of filters are designed, simulations are realized and obtained results are evaluated.

Key-Words: - pure current mode, frequency filters, current mirror, DCCCS

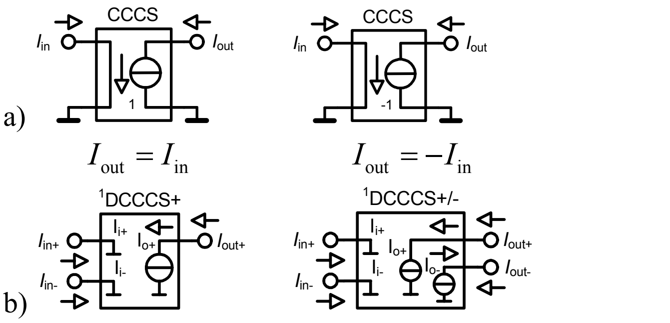
1 Introduction

In a majority of present electronic applications analog circuit structures are used to create an interface between a digital heart of electronic equipment and the analog nature of surrounding world. As the integration density of digital circuits is being increased, its supply voltage is being decreased and the circuits become faster and faster. The analog circuits coexisting with digital ones are forced to go along with this development in the digital world. Therefore they must be capable to operate with lower power supply voltages and consumption, within wider frequency bands while preserving sufficient dynamic range. These requirements can be hardly met using standard electronic structures working in pure voltage mode, where the voltage is the physical quantity carrying the information. Dynamic range of these circuits is strictly tied to the supply voltage, so that it is decreased when the supply voltage is reduced.

In the last decade new circuit structures were designed where both voltages and currents were used to carry information. New active elements like OTAs, CFAs and CCs were used in these networks. These circuits are capable to work up to several tens of MHz of the frequency range. But their dynamic range is still heavily reduced when supply voltage is decreased. Therefore the circuits using currents as their primary quantity can be solution of this problem. Although it is not possible to make the currents independent on the supply voltage, the dependence of the dynamic range of the current on the supply voltage is not so strong like in the case of voltage mode operation.

2 Fundamentals of pure current structures

Pure current active structures are circuits where input and output quantities are currents and currents are also input and output quantities of every active circuit elements. From these constraints it is clear that active elements used in these structures are based on the current mirror principle. Fig. 1 depicts basic types of current mirror-based active elements.



$$I_{\text{out}} = I_{\text{in}} \qquad I_{\text{out}} = -I_{\text{in}}$$

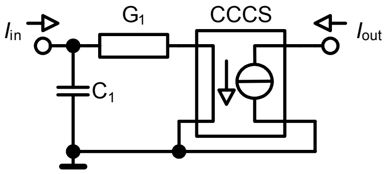
$$I_{\text{out}} = I_{\text{in+}} - I_{\text{in-}} \qquad I_{\text{out+}} = I_{\text{in+}} - I_{\text{in-}},\ I_{\text{out-}} = -I_{\text{out+}}$$

Fig. 1: a) Current mirrors with positive and negative unity transfer, b) differencing current mirrors with single and symmetric current outputs

Other active elements with non-unity current transfer can be designed, i.e. current amplifiers, but it will be difficult to manufacture it with accurate and stable current gain. At present elements from Fig. 1 can be realized by already known elements like current or voltage conveyors, e.g. by CCII+/- or by UCC (Universal Current Conveyor) or by recently designed MFC (MultiFunctional Conveyor).

3 Filtering structures in current mode

Active filtering structures in pure current mode can be designed in a number ways. One possibility is to simulate LC prototype by structures based on current integrators like from Fig. 2.



$$K_1(s) = \frac{G_1}{sC_1 + G_1}$$

Fig. 2: Current-based lossy integrator

Nevertheless, one of the fastest methods is to start from active voltage mode prototype and to transform it into current mode using adjoint network principle.

3.1 Second-order filter structures

The simplest case usable for transformation using adjoint principle is when the original voltage mode circuit contains voltage buffers like in the case of Sallen-Key structure from Fig. 3. CCII- was used to realize required current mirror with negative unit gain.

a)

b)

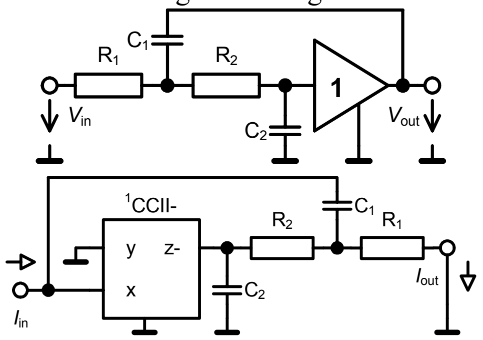


Fig. 3: a) Voltage mode prototype of Sallen Key filter and b) its adjoint counterpart

The transfer function of the adjoint current mode filter is the same like for the voltage mode prototype:

$$K_1(s) = \frac{1}{s^2 R_1 R_2 C_1 C_2 + sC_1(R_1 + R_2) + 1}. \tag{1}$$

Lowpass filter has been designed for this structure with these parameters: Butherworth approximation, f_0 = 1 MHz. Capacitor values were chosen 100 pF. To obtain some interesting outputs the model from Fig. 4 was designed for PSpice simulation software.

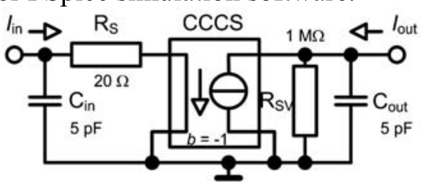


Fig. 4: Model of the current mirror considering some parasitic properties

Results that were obtained by simulations can be seen in Fig. 5.

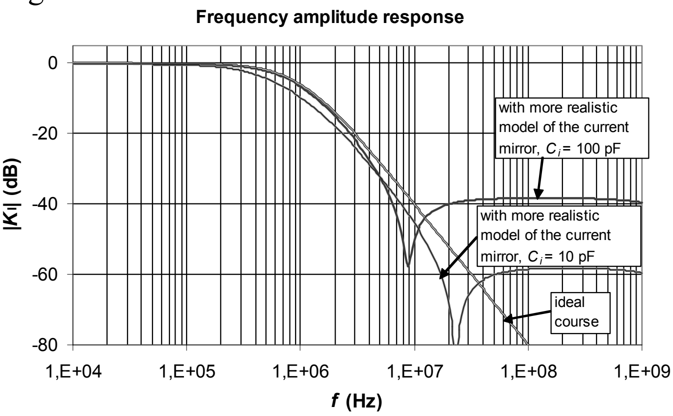


Fig. 5: Frequency responses of the circuit from Fig. 3 b) under different conditions

It is evident from the simulation results that real properties of the active element, i.e. current mirror have strong impact on the circuit performance (attenuation in the stop-band was less than 40 dB). The influence of the current mirror parasitic features was reduced when chosen values of external capacitors were decreased ten times, i.e. from 100 pF to 10 pF (attenuation in the stop-band was increased 10 times, i.e. for 20 dB).

When we exchange the capacitors and resistors in the structure from Fig. 3 b) we obtain high-pass filter with characteristics shown in Fig. 6. It is interesting that in this case the real properties of the current mirror have only moderate influence on the filter performance.

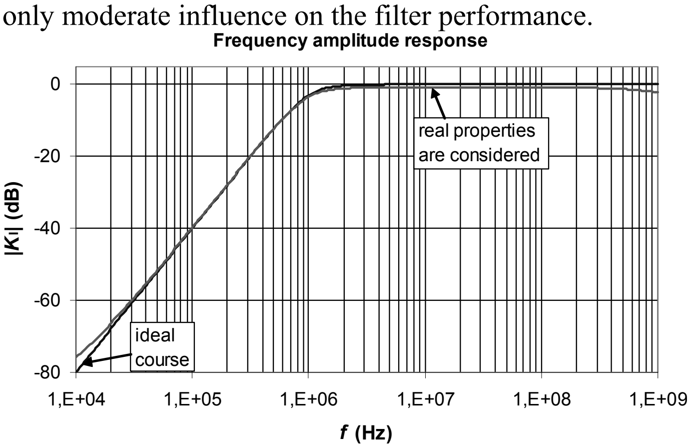


Fig. 6: Frequency response of the second order highpass filter derived from Fig. 3 b)

3.2 Higher-order current mode filter structures

Also higher order filters were designed. The first one is the third order lowpass filter that was also obtained from voltage mode prototype using adjoint principle. The original circuit utilizing CCII- elelments was designed by J. Čajka and realized and measured by V. Zeman. Both the simulations and measurement results published in [4] were very promising. Result structure in pure current mode is shown in Fig. 7.

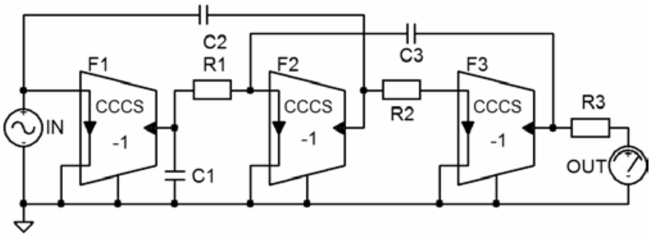


Fig. 7: Third order pure current mode lowpass filter

The frequency characteristic of the network from the Fig. 7 has the form

$$K_{\mathrm{I}}(\boldsymbol{s}) = \frac{1}{\boldsymbol{s}^3 R_1 R_2 R_3 C_1 C_2 C_3 + \boldsymbol{s}^2 R_1 R_2 C_1 C_2 + \boldsymbol{s} R_1 C_1 + 1}. \quad (2)$$

Lowpass filter with cut-off frequency 1 MHz and Tchebyshev approximation with maximum ripple 3 dB in the passband were designed. External capacitors were chosen 100 pF. To find behaviour of the designed filter that is closer to real operation the model of current mirror from Fig. 4 was used. Results obtained by simulations can be seen in Fig. 8. Again we can see strong influence of parasitic features of current mirrors.

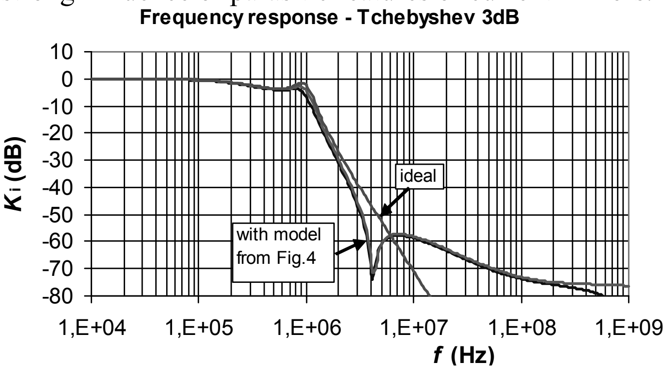


Fig. 8: Frequency responses of the third order Tchebyshev lowpass filter

How the frequency response is changing when the values of either current mirror parasitic properties or values of external passive components are varying can be seen in Fig. 9. Current input serial resistance *R*s of the current mirror (see Fig. 4) is critical for the level of attenuation in stopband. Proper choice of initial values for capacitors also plays important role, see Fig. 10.

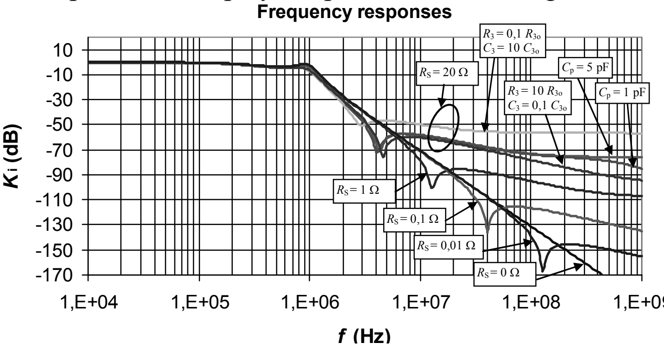


Fig. 9: Frequency responses of the third order lowpass filter under different conditions

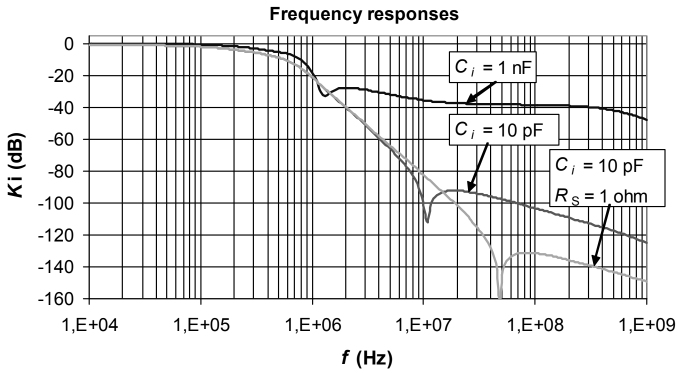
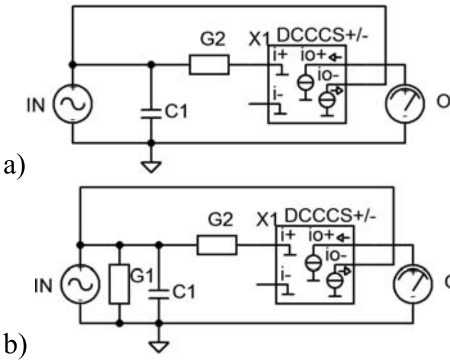


Fig. 10: Influence of the choice of capacitor values in structure from Fig. 7

3.3 Filtering structures with DCCCSs

It could be seen from previous results that structures in the pure current mode do not improve performance of analog filters in such extent as it could be expected. Real properties of the current mirrors together with improper choice of external component values can degrade the filter performance. The influence of parasitic features of current mode active elements can be reduced by suitable structures. Difference current controlled current source with bipolar current outputs (DCCCS+/-) is very promising active element for such structures. Lossless and lossy integrators with DCCCS are depicted in Fig. 11.



a) $K_{\mathrm{I}}(\boldsymbol{s}) = \dfrac{G_2}{\boldsymbol{s}C_1}$

b) $K_{\mathrm{I}}(\boldsymbol{s}) = \dfrac{G_2}{\boldsymbol{s}C_1 + G_1}$

Fig. 11: Lossless and lossy integrators with current mirrors with difference input and symmetrical output

Several second order filtering structures with DCCCSs were designed like bandpass filter from Fig. 12.

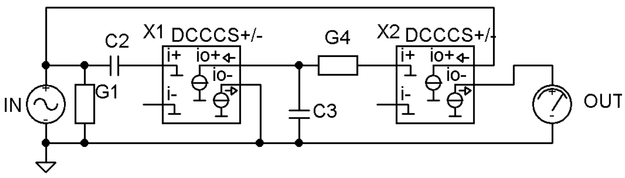


Fig. 12: Second order bandpass filter with DCCCSs

Its transfer function is

$$K_{\mathrm{I}}(\boldsymbol{s}) = \frac{\boldsymbol{s} G_4 C_2}{\boldsymbol{s}^2 C_2 C_3 + \boldsymbol{s} G_1 C_3 + G_1 G_4}. \quad (3)$$

To be capable to compare properties of the structures with DCCCSs with the filters analyzed above, we also designed third order lowpass filter with the same transfer function (2) and the same approximation and cut-off frequency. The result circuit is shown in Fig. 13.

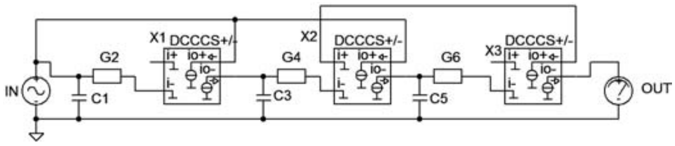


Fig. 13: Third order lowpass filter with DCCCSs

Model of DCCCS had to be designed for PSpice environment. It is shown in Fig. 14 and corresponds to that from Fig. 4 for single input and single output.

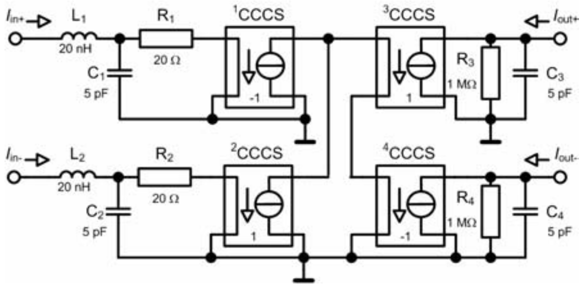


Fig. 14: Model of DCCCS for PSpice environment

The filter was simulated for three choices of capacitor values. From Fig. 15 we can see two things:

- ♦ an influence of parasitic features is quite small,
- ♦ the larger values of the external capacitors, the better performance,
- ♦ the error caused by the parasitic properties of the network can be easily optimized by recalculation of the values of external components.

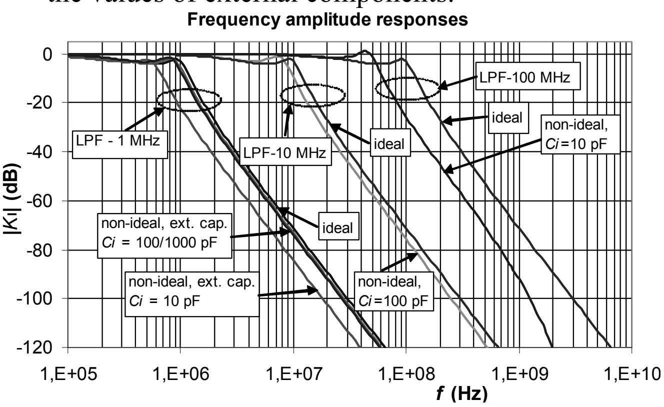


Fig. 15: Frequency responses of the network - Fig. 13

The same filter structure was also designed for cut-off frequencies 10 and 100 MHz. Although the influence of the parasitic features is stronger, the response can be corrected by the change of values of external capacitors and resistors. In [1] and [5] an idea of new active element called MFC was presented. Fig. 16 shows realization of designed filter with this element.

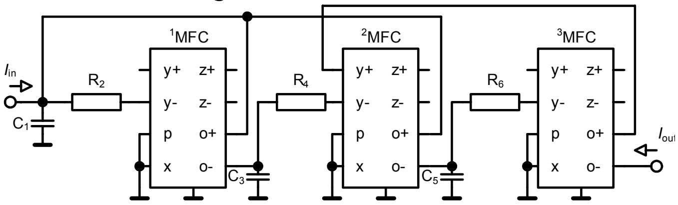


Fig. 16: Realization of the filter from Fig. 13 using MFCs

4 Conclusion

The paper presented the pure current approach to the filter design. It was shown that neither this type of filtering circuits is without design problems. Parasitic features can have strong impact on the filter behaviour. But some structures are quite promising and it will be worth to realize them and to measure their properties in real operation.

Further effort in this area will be focused on the design of internal structure of multifunctional conveyor that can be used as DCCCS in pure current filter structures. Other structures working in pure current mode will be explored and analyzed.

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