Some Variants Current Mode Filter via Commercial Integrated Circuits and its Proprieties

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Abstract— **The current mode signal processing is useful technique for frequency filters. As is best known, some biquad structures are characterized by a degradation of the attenuation at high frequencies. Loss of attenuation is one proprieties Sallen-Key low-pass filter not only in voltage, but in current mode, as well. Some possibilities to solve this disadvantage are described in this paper.**

Keywords—*current conveyor, transimpedance amplifier, current-mode network, current mode filter.*

I. INTRODUCTION

Last days the current mode signal processing is very useful technique for increasing of analog networks, namely frequency filters [1], [2] and more others. Consider Sallen - Key low pass filter, which is depicted in Fig.1.

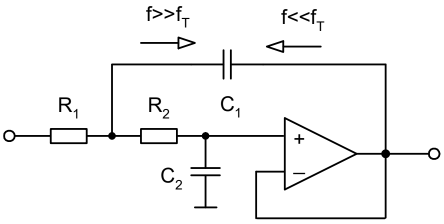

Fig.1 LP-SK filter in voltage mode

To transformation VM into CM the adjoint transformation is applied to active circuits (see Fig.2), where OpAmp is connected as voltage follower. The foundation of this method was given in [3], [4], [5]. When the adjoint transformation is used (see Fig.2), where the same circuit is excited in node 1 in voltage mode (VM) by voltage source and in the node 2 in current mode (CM) by the current source, will remain the same disadvantage, if the circuit in current mode (see Fig.2) will be designed this way.

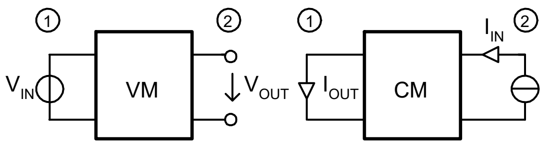

Fig.2 The adjoint transformation principle

As an active element in CM can be used one part of transimpedance amplifier, ie. the positive current conveyor CCII+, which is connected as an current follower. The output transistor collector current I_C is directed by transistors T_2, T_4 i.e. by the current x node only (see Fig.3).

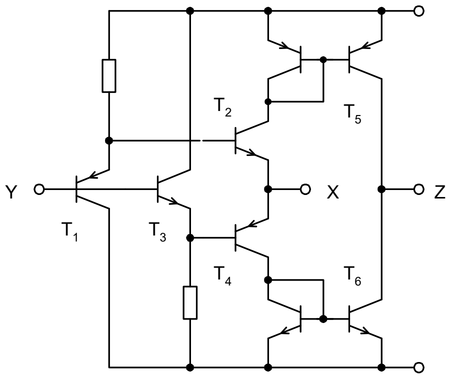

Fig.3 Simplified current conveyor schematic diagram

If CCII+ will be realized from commercial integrated circuits, can be used commercially available transimpedance amplifier type AD 844 [4], [6], which the following basic parameters are listed in [6]. Its higher y-terminal impedance is R_y = 10 MΩ, the second one high z-terminal impedance is R_z = 3 MΩ and the (very relatively high) x-terminal resistance is R_x = 50Ω.

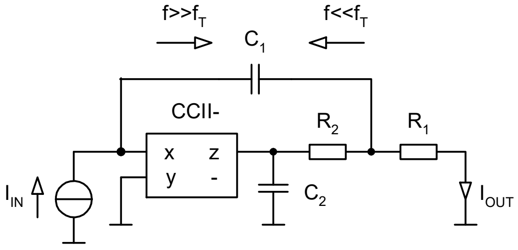

Fig.4 LP-SK filter in current mode after adjoint transformation

At the higher frequencies, where the capacitors impedance is equal to zero, the output current I_{OUT} is given by formula (1)

$$I_{OUT} = \frac{I_{IN}}{G_{IN} + G_{OUT} + G_2 + G_1} \cdot G_1 \quad (1)$$

Because usually is (2)

$$G_{IN} << G_{OUT}, G_{IN} << G_2, G_{IN} << G_1 \tag{2}$$

Thus the current transfer is (3)

$$\frac{I_{OUT}}{I_{IN}} = \frac{G_1}{G_{IN}} \tag{3}$$

The current transfer magnitude at higher frequencies is (4)

$$\frac{I_{OUT}}{I_{IN}} \approx \frac{G_1}{20 \cdot 10^{-3}} \tag{4}$$

and its Bode plot is depicted in Fig.5.

Fig.5 Bode magnitude frequency response

For the values $R_1 = R_2 = 10^3 \Omega, C_1 = 10^{-9} F$, $C_2 = 2 \cdot 10^{-9} F$ the simulation result, i.e. for the magnitude response, is depicted in Fig.6. The AD 844 parameters described above are used for simulation.

The program SNAP for this simulation (and/or verification) and for following simulation was used as well.

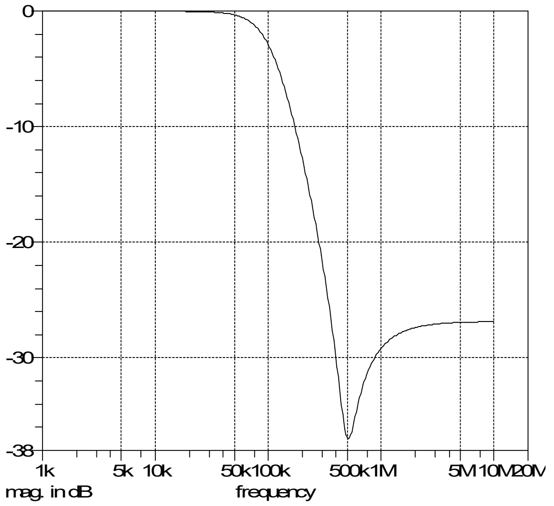

Fig.6 Simulation result - original circuit magnitude response (circuit from Fig.4)

Because this circuit consist from positive conveyor CCII+, it is necessary to connect the two AD 844 into the cascade (see Fig.7) to CCII- realization.

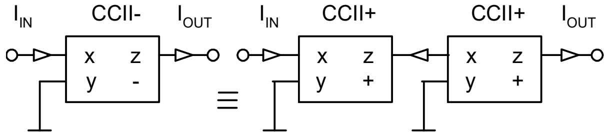

Fig.7 Realization CCII- from a pair of CCII+

Figure 5 and Fig.6 show the disadvantage of the mentioned circuit [7] - after exceeding a certain frequency, the attenuation no longer increases but decreases and at the highest frequencies it settles at a constant value. The cause is the capacitor, which as a bilateral circuit element passes the signal in both directions. The attenuation stabilizes at a value of approx. 36.65 dB as shown by equations (5) and (6)

$$I_{OUT} = \frac{I_{IN} \cdot \dfrac{r_X \cdot \dfrac{R}{2}}{r_X + \dfrac{R}{2}}}{R} = I_{IN} \cdot \frac{\dfrac{r_X}{2}}{r_X + \dfrac{R}{2}} \tag{5}$$

$$K_I = 20 \cdot \log \frac{\dfrac{r_X}{2}}{r_X + \dfrac{R}{2}} = 20 \cdot \log \frac{25}{50 + 500} =$$
$$= 20 \cdot \log 0{,}045 = -26{,}93 \mathrm{dB} \tag{6}$$

where R are the resistances in the filter and rx is the input resistance of the low-ohm conveyor input and K_I is the current transfer at the highest frequencies. The result of the equation (6) is in very good agreement with the simulation result in Fig.6 (see frequency 10 MHz).

II. PROPOSED SOLUTIONS

Described disadvantage can be easily eliminated by including a unilateral element that transmits the signal in only one direction, which is connected in series with the capacitor C_1. One solution option is described for VM in [7]. Using adjoint transformation is circuit depicted in Fig.8.

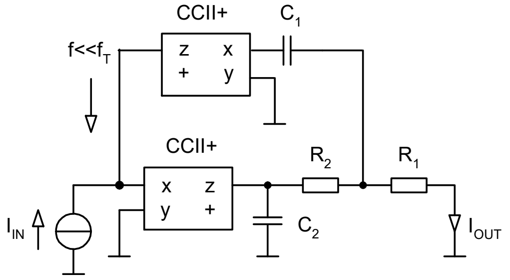

Fig.8 Proposed solution

The collector current of transistors T_5, T_6 (i.e. current I_z) is controlled to the bases by the current derived from the collector currents of transistors T_2, T_4 (i.e. by current Ix) but not vice versa [8], [9], [10]. Therefore, the conveyor repeats the current Ix to Iz, but not vice versa, so that included in the branch with capacitor C_1, only the current from the output to the input passes through it and not the other way around. Since the reverse transmission of the signal does not occur, the magnitude attenuation must theoretically grow monotonically with frequency according to Bode plot depicted in Fig.9.

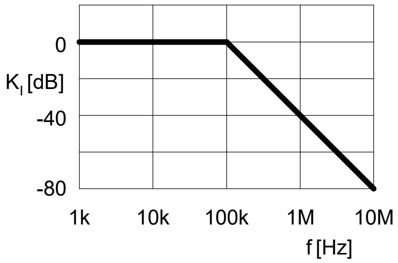

Fig.9 Proposed circuit Bode magnitude plot

This theoretical conclusion is confirmed by the simulation of the circuit from Fig.8, the result of simulation, i.e. the magnitude response, is shown in Fig.10.

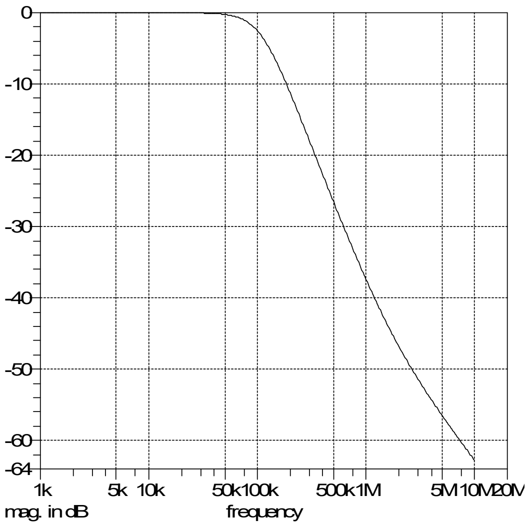

Fig.10 Proposed circuit simulation result – magnitude response

The AD 844 parameters described above (see part I. Introduction) are used for simulation. Because CCII+ is used, the input I_{IN} and output current I_{OUT} are in opposite. It means the output signal (current) is inverted. This fact is verified by simulation result, as is depicted in Fig.11 where is original circuit phase response and Fig.12 where is proposed circuit phase response.

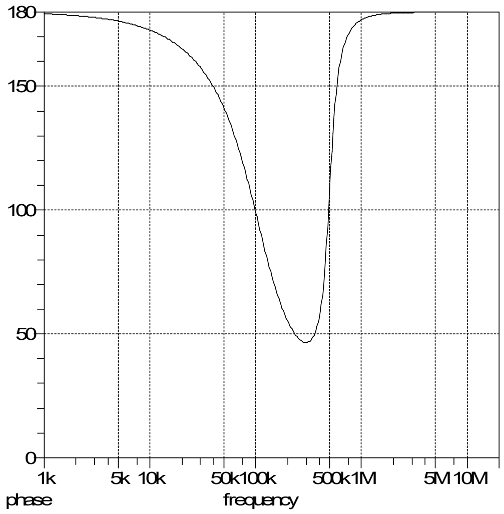

Fig.11Original circuit phase response

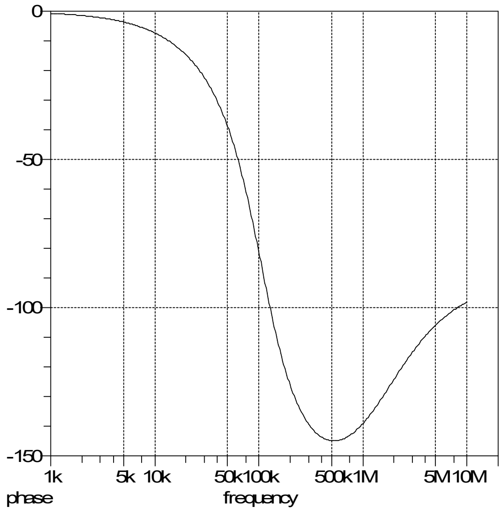

Fig.12 Proposed circuit phase response

The opposite phase can be disadvantage in some cases, and can be eliminated follows by another CCII+ (i.e. another AD 844), which is connected at the output. In this case the input filter impedance is defined as input impedance of third CCII+, i.e. relatively high x-terminal resistance R_x = 50Ω, but it is known.

The second one solution is depicted in Fig.13.

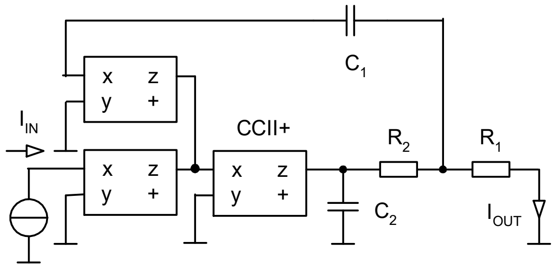

Fig.13 The second one proposed solution

Its magnitude response is in Fig.14, where is simulation result.

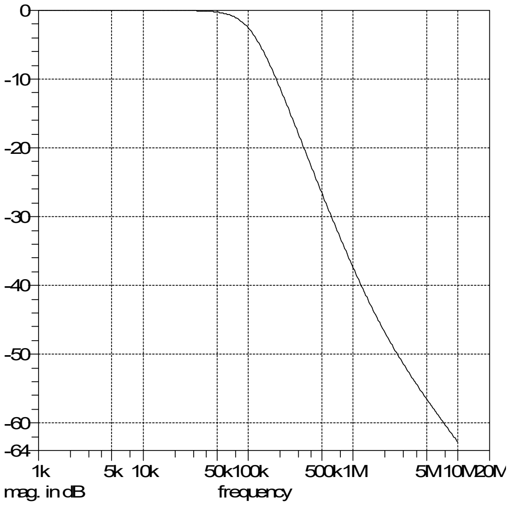

Fig.14 Magnitude response circuit from Fig.13

Figure 15 shows phase response, as we can see, Fig.10 and Fig.14 are identical.

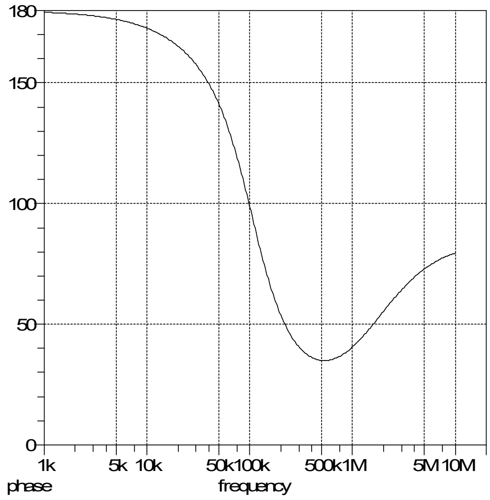

Fig.15 Proposed circuit phase response

Figure 16 depicted circuit with double CCII+ i.e. with two AD 844, second one solution with three transimpedance amplifiers is shown in Fig.17.

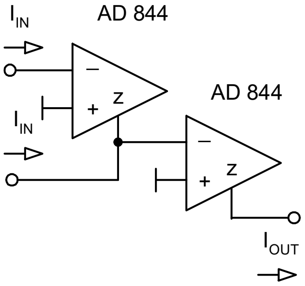

Fig.16 Solution with two transimpedance amplifiers

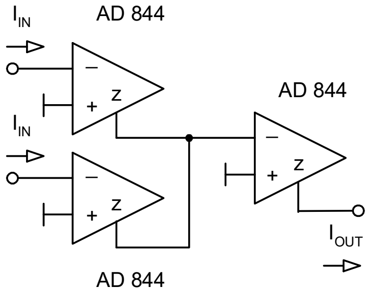

Fig.17 Solution with three transimpedance amplifiers

The AD 844 triplets can be realised as an hybrid integrated circuit, resulting circuit diagram with this proposed hybrid integrated circuit is depicted in Fig.18.

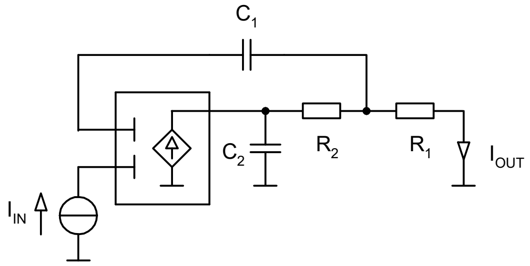

Fig.18 Final circuit diagram.

III. CONCLUSION

Finally, the magnitude and phase responses, i.e. simulation results (i.e. Fig.) are compared. As we can simply see, the solution contained three transimpedance amplifiers and circuit contained CCII- are equal. Differences in phase response after 500 kHz are irrelevant, because the attenuation is 25 dB, it means this frequency band is the filter stop band. It means in stop band is not useful signal.

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