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CURRENT FILTERS DESIGNED USING A CONTROLLED CURRENT CONVEYOR CCC

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Abstract: The main task of that paper consists in the solution to some problems of active frequency filtering of current signals. The RC-active current filters of the first and the second order, designed using a second generation current conveyor CCII±, have been presented. Those filters of the second order designed using only one CCII±, without positive feedback, have a quality factor ≤ ½. Because of that authors have proposed a new model of an amplifier – a Controlled Current Conveyor CCC. The proposed structures have been tested by means of the simulation programme PSpice using macromodels of the CCC.

Keywords: Frequency Filtration, Current Filters, Current Conveyors, CCII, MTCCII.

1 Introduction

Frequency filtration of electric analogue signals is an issue which have bothered engineers for many years. The filtrated signal is more often a voltage one, however, it is often necessary to design the structure for which parameters of transmission of other electric signals such as active power (matching filters) or current strength (current filters) [1], [3], [4], [13]. A very fast developing technique of digital systems has not eliminated, as it was thought, the need of the use of analogue systems but only impose on them very high requirements. Analogue systems cooperating with digital ones must work at lower and lower supply voltage and at the same time higher and higher bandwidth (reaching even hundreds MHz). The fulfilment of those requirements became more difficult in

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the group of classic voltage amplifiers. Lately systems processing current signals characterised among others by

- the possibility of amplifying very small signals,
- wide bandwidth
- low consumption of active power,
- simple inner construction,
- large dynamics,
- gain independent from system supply voltage

has become very important.

Such an approach to the signal theory causes that research connected with current filters taking into account mainly such disciplines as an analysis of filter sensitivity, the search of new structures and active systems allowing for their realisation becomes very crucial [11], [12].

2 Second generation current conveyor CCII±

A second generation current conveyor CCII± is a universal wide-band analogue amplifier allowing for an alternative approach towards signal filtration on the basis of a classic operational amplifier OA taking filtration of current signals [9], [10] into consideration. That system has three terminals marked more often by letters XYZ, and its ideal equivalent circuit diagram on the basis of controlled source is presented in fig.1

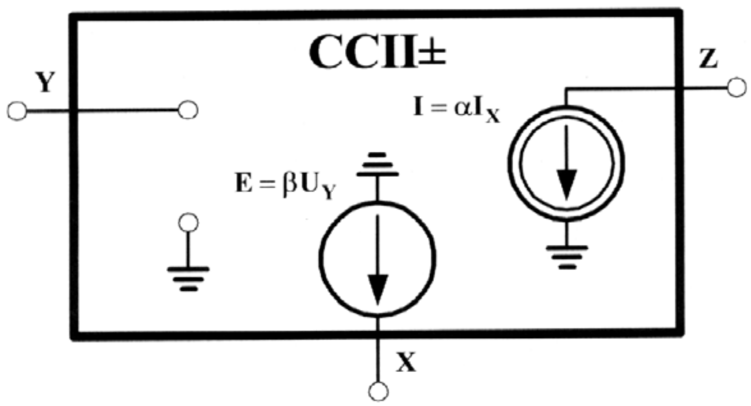

Fig. 1. Second generation current conveyor

$$\begin{bmatrix} I_Y \\ U_X \\ I_Z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ \beta & 0 & 0 \\ 0 & \alpha & 0 \end{bmatrix} \begin{bmatrix} U_Y \\ I_X \\ U_Z \end{bmatrix} \tag{1}$$

where coefficients: $\beta = 1$, $\alpha = \pm 1$.

Internal structure of CCII± is completely different from the structure of an ideal OA. It causes the necessity of outworking new analogue implementation of transmission function which for the realisation of current filters are limited to non-inductive, high impedant, in input, and (or) low impedant, in output, structures realising current-current transmittance (called current transmittance) $K_i(s)$ of the first and the second order [2], [5].

3 First order current filters with a use of CCII±

The first order filters have more often insufficient parameters (attenuation in a band-stop) for the realisation of assumed aims of filtration. However, filtrating structures of the first order are necessary as elementary structures used in the realisation of filters of higher odd orders. Structures of the first order can be only low-pass, high-pass and all-pass structures (phase shifter). For the realisation of band-pass and band-stop filters elementary structures are the one of the second order. For the construction of current filters of the first order, systems allowing for the realisation of the following current transmittance should be applied:

Table 1

Type	**LP**	**HP**	**AP**
$K_i(s)$	$\frac{K_0}{As+1}$	$\frac{K_0 s}{As+1}$	$\frac{K_0(As-1)}{As+1}$

where: K_0 is filter gain

For the active realisation of such current transmittance four-admittant active circuit with one CCII± presented in fig.2 is sufficient.

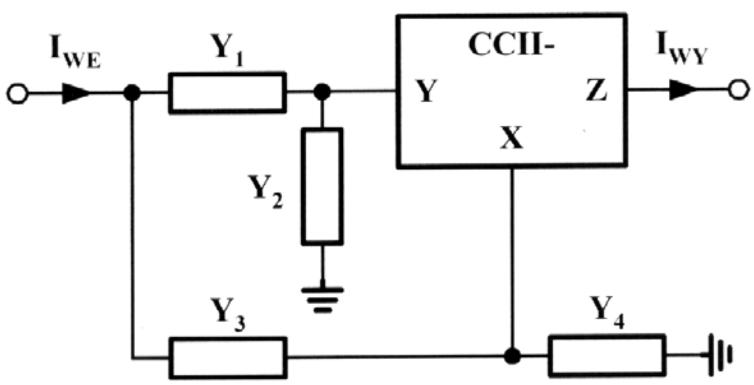

Fig. 2. Four-admittant active circuit with one CCII±

Current transmittance of such a system looks as follows:

$$K_i = \frac{I_{WY}}{I_{WE}} = \frac{Y_2Y_3 - Y_1Y_4}{Y_2Y_3 + Y_1Y_2}. \quad (2)$$

From the above-mentioned dependence it comes that at the suitable selection of admittance any structure of the first order filtrating current signals [3], [6], [11] can be realised by means of such a circuit. For example for the realisation of a LP filter it is assumed:

Y1 = sC1, Y2 = G1, Y3 = G3, Y4 = 0,

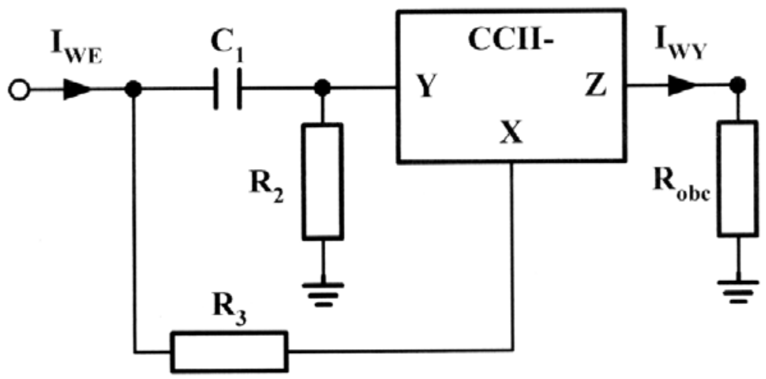

Fig. 3. Active first order LP current filter

$$K_i(s) = \frac{G_2G_3}{G_2G_3 + sC_1G_2}, \quad (3)$$

And after suitable conversions:

$$K_i(s) = \frac{1}{1 + sR_3C_1}. \quad (4)$$

It can be noticed that a filter having such structure is not sensitive for the changes of resistance R_2.

4 Second order current filters with a use of CCII±

Structures of the second order realising current transmittance, presented in literature, are structures having more than two CCII±, with a significant number of connected admittance and positive feedback. Such an approach to the structure design causes huge complication of the system. Analysing the circuit in fig.2 and its current transmittance (2), one can think whether it is possible to realise a second order current filter by the use of such a simple construction [11]. For the construction of such filters, circuits allowing for the realisation of the following current transmittance must be used:

Table 2

Type	**LP**	**HP**	**BP**
$K_i(s)$	$\frac{K_0}{As^2+Bs+1}$	$\frac{K_0As^2}{As^2+Bs+1}$	$\frac{K_0Bs}{As^2+Bs+1}$
Type	**BS**	**AP**	
$K_i(s)$	$\frac{K_0(As^2+1)}{As^2+Bs+1}$	$\frac{K_0(As^2-Bs+1)}{As^2+Bs+1}$	

where: K_0 is filter gain.

To active a denominator of transmittance $K_i(s)$ of the second order, some of admittances Y (different for different types of filters) must be replaced by parallel connections of resistance and capacitance. In a general case all admittances can be replaced by parallel connections:

$Y_1 = G_1 + sC_1$, $Y_2 = G_2 + sC_2$, $Y_3 = G_3 + sC_3$, $Y_4 = G_4 + sC_4$.

Substituting assumed admittance to the dependence expressed by a formula (2) it can be achieved:

$$K_i(s)=\frac{(G_2G_3-G_1G_4)+(C_3G_2-C_4G_1+C_2G_3)s+(C_2C_3-C_1C_4)s^2}{(G_1G_2+G_2G_3)+(C_2G_1+C_1G_2+C_3G_2+C_2G_3)s+(C_1C_2+C_2C_3)s^2}.$$

For the simplification of the analysis, further consideration will be carried out for the assumptions of a LP filter. Those assumptions can be realised by a suitable selection of passive elements, so that the order of a numerator equals zero. The exemplary transformation of the equation for the achievement of a LP filter presents a formula:

$$K_i(s)=\frac{(C_2G_1G_2-C_1G_2^2)}{(C_2G_1G_2-C_1G_2^2)+C_2^2G_1s+C_1C_2^2s^2}. \tag{5}$$

Analysing the dependence presented by a formula (5) one can draw a conclusion that the realisation of a LP current filter is possible. However, it is necessary to think over whether a Q factor of the above-mentioned system will be high enough so that the realisation of any filter according to assumed mathematical approximations (e.g. Butterworth's or Chebyschev's) is possible.

Transmittion of a LP filer is shown by a general formula:

$$T(s)=\frac{K_0}{\left(\frac{1}{\omega_0^2}\right)s^2+\left(\frac{1}{\omega_0 Q}\right)s+1}. \tag{6}$$

Comparing equations (5) and (6) and transmitting them with respect to G_2 it can be achieved:

$$G_2=\frac{C_2\omega_0\left(1\pm\sqrt{1-4Q^2}\right)}{2Q}. \tag{7}$$

Out of an equation (7) it can be directly concluded that to enable the realisation of the filter, a Q factor cannot exceeds ½. Unfortunately, such a low Q factor (corresponding to a daisy chain of two passive filters RC) does not allow for the realisation of filters having given mathematical approximations of characteristics of transmittance modulus [1], [3], [4], [13].

Unfortunately, the realisation of a second order current filter having a Q factor over ½ is not possible by the use of the structure presented in fig. 2. That state is connected with the lack of circuit inertia. That structure does not have inductance L in the initial assumptions, positive feedback, and internal gain of CCII± does not exceed a unit.

5 Controlled current conveyor CCC

As it is confirmed in the section 4 of the paper it is not possible to realise filters having a Q factor exceeding ½. by means of the structure presented in fig.2. The structures designed on the basis of CCII± are multi-admittant and multi-conveyor ones and enriched by positive feedback. It causes not only the increase of the degree of complication of systems but also the increase of the sensitivity for changes of values of passive elements. Positive feedback causes instability of real systems, self-generation, and first of all noise gain appearing in the circuit output. Those problems caused that modifications of analogue amplifiers have appeared in literature. The popular solution is an increase of the number of conveyor terminals. Such a conveyor is called a Multiterminal Current Conveyor - MTCCII [7], [12]. Authors propose to develop properties of CCII± by the assumption that its coefficients of current transmission α and voltage β can be controlled and have any, finite, positive and negative real values. Such an amplifier is called a **C**ontrolled **C**urrent **C**onveyor - **CCC**.

6 Second order current filters with a use of CCC

If in the structure in fig.2. CCII± will be replaced by a controlled current conveyor CCC, current transmittance of that structure will be presented by the formula:

$$K_i = \frac{I_{WY}}{I_{WE}} = \alpha \cdot \frac{Y_2 Y_3 - Y_1 Y_4 \beta + Y_1 Y_3 (1-\beta)}{Y_2 Y_3 + Y_1 Y_2 + Y_1 Y_3 (1-\beta)}. \tag{8}$$

The suitable choice of admittance Y and gain coefficients should allow for the realisation of any second order current filter. That assumption will be proved on the example of a LP filter.

Example
Design a LP filter (according to the scheme in fig.2) with a use of a CCC.
Data: $f_0 = 10$ kHz, $\vartheta(1) = -3$ dB,
approximation → Butterworth's (Q = 0.707).

Solution:
Transmittance of such a filter is displayed by the following formula:

$$T(s) = \frac{1}{\left(2.533\cdot10^{-10}\right)s^2 + \left(2.251\cdot10^{-5}\right)s+1}. \qquad (9)$$

After substituting the following admittance to the formula (8):
$Y_1 = sC_1$, $Y_2 = G_2 + sC_2$, $Y_3 = G_3$, $Y_4 = G_4$
and $\alpha = 1$, and also assuming:

$$G_4 = \frac{C_1G_3(1-\beta) + C_2G_3}{C_1\beta} \qquad (10)$$

it can be achieved:

$$K_i(s) = \frac{1}{\left(\frac{C_1C_2}{G_2G_3}\right)s^2 + \left(\frac{C_1G_2 + C_2G_3 + C_1G_3(1-\beta)}{G_2G_3}\right)s+1}. \qquad (11)$$

Comparing formulas (9) & (11) and assuming:
$C_1 = 1$ nF, $C_2 = 10$ nF, $R_2 = 10$ kΩ,
it has been counted:
$R_3 = 2.533$ kΩ, $R_4 = 11.416$ kΩ, $\beta = 9.002$

Effectiveness of filter work has been checked with a use of a simulation programme PSpice 9.2 [8] for which the ideal model CCC has been created.

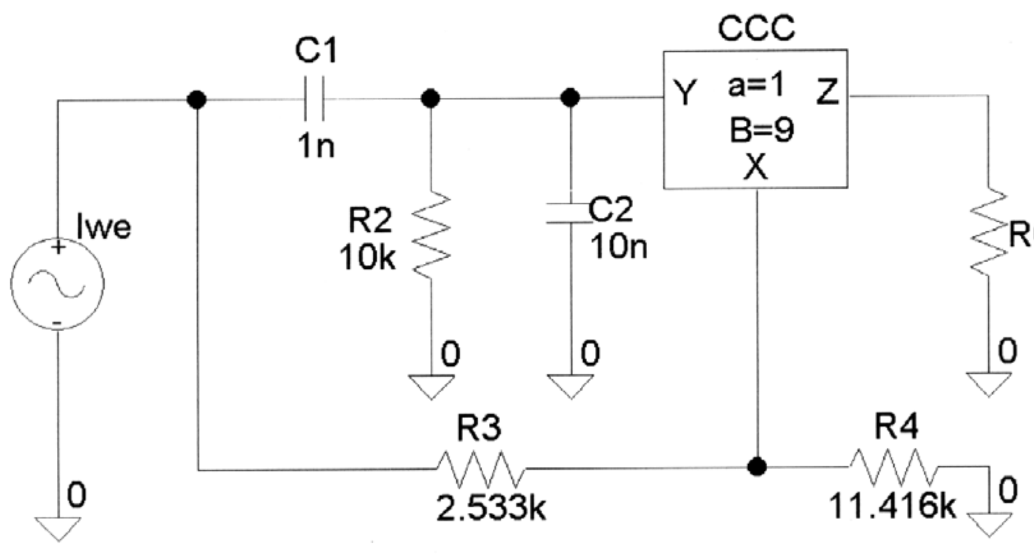

Fig. 4. Scheme of a simulated circuit

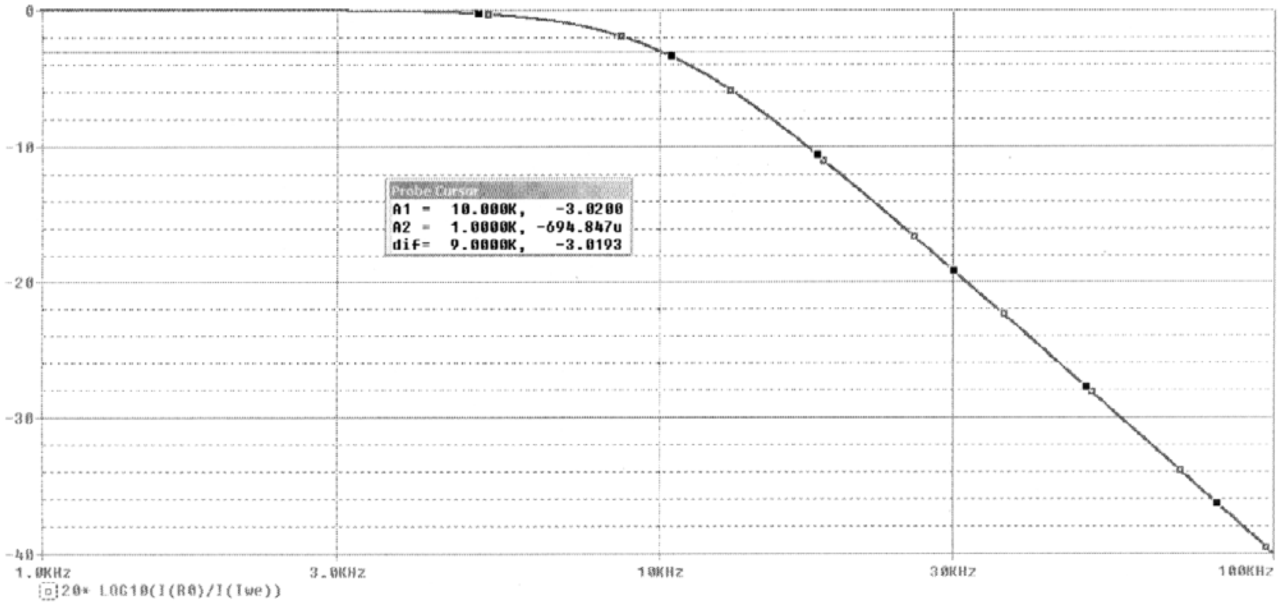

Fig. 5. Characteristics of a current transmittance modulus of a simulated circuit

As it has been shown in the example 1 the realisation of current filters having a Q factor exceeding ½ in the structure with one controlled current conveyor CCC is possible. The structure of a LP filter consists of five joined passive elements and troublesome positive feedback do not appear in it. The control of a α coefficient is not necessary but allows for the choice of unit gain of the structure K_0, and what follows among others: simulations of energetic system matching [1], [4]. The crucial influence on current transmittance of the structure in fig.2 has a voltage transmission coefficient β which control can be made by enriching the classic system CCII± by a multiplying system.

7 Conclusion

Because of numerous advantages of signal transmittion analogue current signal processing has become very important lately. The application of such electronic analogue amplifiers others than operational ones, in transmittance is necessity connected mainly with bandwidth. It becomes necessary to work out the structures of the first and second order (parallel to the structures based on an OA) allowing for easy chain connections [5]. Amplifiers such as second generation current conveyors CCII± enriched in systems by elements RC seem to be ideal for such applications. Unfortunately the lack of internal gain in CCII± and the assumption of the lack of inductance L in systems do not allow for the realisation of current filters of higher orders having a Q factor exceeding ½ lacking suitable positive feedbacks. One should not leave design work and searches of suitable systems consisting of e.g. electronic amplifiers of various types such as a four terminal floating nullor FTFN, a current operational amplifier COA, or also a controlled current conveyor proposed in the paper [7],

[11]. Such systems many a time worked out theoretically and proposed even a few dozen years ago do not reach mass production. One cannot forget that the world surrounding us is dominated by analogue signals and analogue electronics cannot be disregarded and only analogue systems allowing for unconstrained cooperation with new and commonly used systems of digital electronics should be searched.

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