ARC FILTERS USING ONLY FOLLOWERS

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Abstract

Several structures of the active RC filters using non-inverting voltage unity-gain followers and dual current positive followers are given in this paper. These structures can be suitable implemented by the positive second generation current conveyors or by the transimpedance operational amplifiers. A symbolical analysis using SNAP and a simulation by PSpice have been made to confirm the given theoretical approach.

Keywords

analogue signal processing, active RC filters, voltage and current unity-gain followers.

1. Introduction

The recent progress of the current mode technology [3] has allowed the implementation of new monolithic IC active components and / or functional blocks, with higher frequency operation and wider dynamic range as compared with the classical opamps.

Such components are e.g. the second generation current conveyors (CC II) and the transimpedance operational amplifiers (TIOA) in Fig. 1.

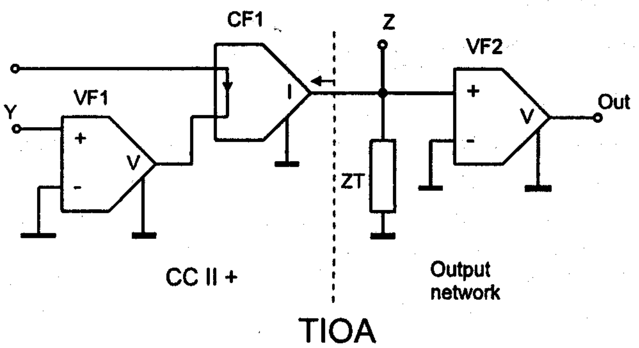

Fig. 1 Model of the basic current conveyor CC II and the transimpedance operational amplifier using voltage and current followers

The new functional block titled differential voltage current conveyor (DVCC) [4], which is a fifth-port (Fig. 2a) based on the CC II, has a model given in Fig. 2b.

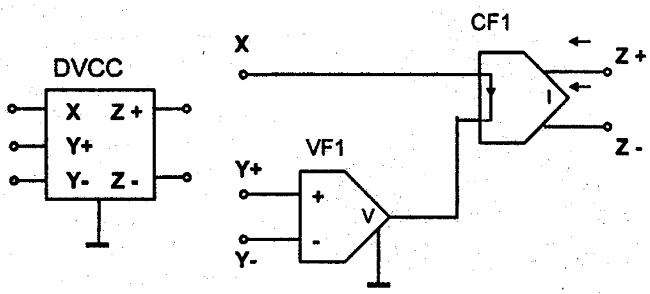

Fig. 2. Differential voltage current conveyor
a) block symbol,
b) suitable model

On the face of these models (Fig. 1 and Fig. 2) one can see, that the both mentioned functional blocks consist in detail of the two types of subcircuits only, namely the voltage and current followers. It is the reason that the realisation of given transfer functions using the followers has recently received considerable attention in the literature [1], [2]. The method allows an uniform approach and simple design.

2. Voltage and dual current followers

The unity gain cells given above (Fig. 1) are namely, **voltage follower** (VF) described by

$$i_x = 0, \quad v_x = (\pm)\, v_y\,, \tag{1}$$

and the dual **current follower** (CF) described dually

$$v_x = 0, \quad i_z = (\pm)\, i_x\,. \tag{2}$$

Note that the ports of the buffers can be connected as follows:

- single input and single output (SISO),
- differential input and single output (DISO),
- single input and differential output (SIDO),
- differential input and differential output (DIDO).

Furthermore our attention is constrained on the non-inverting or positive followers only, specially on the positive current followers (CF+), with differential input and single output (DISOCF+). The reason is, that these structures current follower can be easy implemented by the commercially available component AD 844, what is quite different to the reference [1].

These followers have become as essential elements in the analogue signal processing, namely in the voltage and in the current mode too. They have brought novel simple conception in simulation process and circuit design, which was firstly given in references [1] and [2].

3. Integrators using followers

For the purpose of the synthesis of n-order filters, we are taking now, 1-st order low-pass filter, as a suitable building subcircuit. The Fig. 3 shows a conventional **voltage integrator** using voltage and current followers, namely the VF1 and the CF1. The transfer function of this circuit has the single form

$$K = \frac{V_{out}}{V_{inp}} = \pm\frac{R_2}{R_1}\frac{1}{1+sC_1R_2}. \qquad (3)$$

If the resistor R_2 is not presented in the circuit of Fig. 3 a pure integrator is obtained, when

$$K = \frac{V_{out}}{V_{inp}} = \pm\frac{1}{sC_1R_1} \qquad (4)$$

and in time domain

$$v_{out}(t) = \frac{1}{R_1C_1}\int v_{inp}(t)dt. \qquad (5)$$

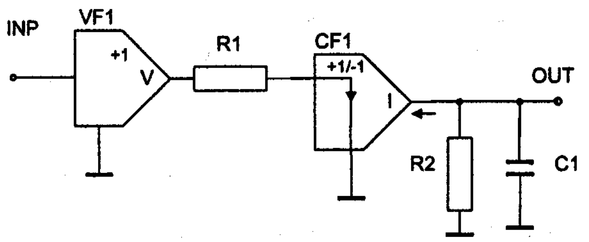

Fig. 3 Voltage integrator using followers

A modification of the above integrator for the conveyors CC II (+) is given in Fig. 4.

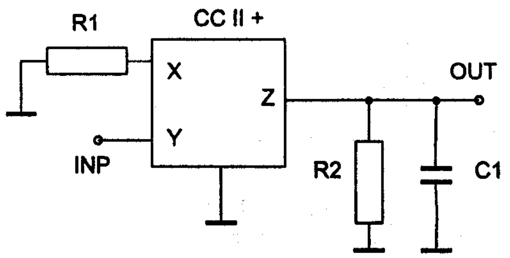

Fig. 4 Voltage integrator using current conveyors

Using the adjoint transformation from [3], the **current integrator** described by

$$i_{out}(t) = \frac{1}{R_1C_1}\int i_{inp}(t)dt. \qquad (6)$$

is proposed as shown in Fig. 5.

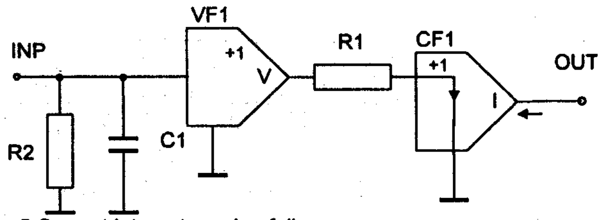

Fig. 5 Current integrator using followers

4. Biquadratic structures with followers

Other building block is the biquad. The first proposed biquadratic structure **B4F-A**, using four followers, namely two voltage ones (VF1, VF2) and two dual positive current ones (CF1, CF2), both with differential input and single output, is shown in Fig. 6. The routine symbolical nodal analysis, aided by computer tool SNAP, results in the following transfer function for the ***Out-A***

$$K_A(s) = \frac{V_{out}^{(A)}}{V_{in}} = \frac{Y_1Y_2}{Y_1Y_3+Y_3Y_5+Y_2Y_4}, \qquad (7)$$

and similarly for the ***Out-B***

$$K_B(s) = \frac{V_{out}^{(B)}}{V_{in}} = \frac{-Y_1Y_3}{Y_1Y_3+Y_3Y_5+Y_2Y_4}. \qquad (8)$$

It is evident, that the coefficients of the transfer functions are given by the element values quite independently. This is the basic advantage of the structure B4F-A compared with the B4F-B, given below.

If the gains of the followers are not exactly unity, but

$$E = 1+\delta v \qquad \text{and} \qquad F = 1+\delta i, \qquad (9)$$

then the transfer function (7) would be

$$K_A(s) = \frac{-E_1E_2F_2Y_1Y_2}{Y_1Y_3+Y_3Y_5+E_1E_2F_1F_2Y_2Y_4}, \qquad (10)$$

what allows to evaluate the associated tracking errors and corresponding real inherent features.

The other biquadratic structure **B4F-B** using four followers is shown in Fig. 7. There the first current follower CF1 has non-standard connection of the output port, what brings a difficulty with practical implementation, e.g. using the TIOA. A modification of this structure has been given in [2], namely using one negative (CF1) and one positive current follower (CF2), both standard grounded.

The symbolical analysis of the circuit in Fig. 7 results in the simpler transfer function as follows

$$K_A(s) = \frac{V_{out}}{V_{in}} = -\frac{Y_1Y_3+Y_2Y_6}{Y_3Y_4+Y_5Y_6}. \qquad (11)$$

To obtain a biquadratic function from (11), some from the Y must be taken as a parallel connection of two RC elements, what is illustrated in Tab. 2.

Other structure using only three followers was presented in [1]. Similar configuration **B3F** is given in Fig. 8. There the analysis yields the transfer functions with similar form as the above (7), (8) for the B4F-A, namely

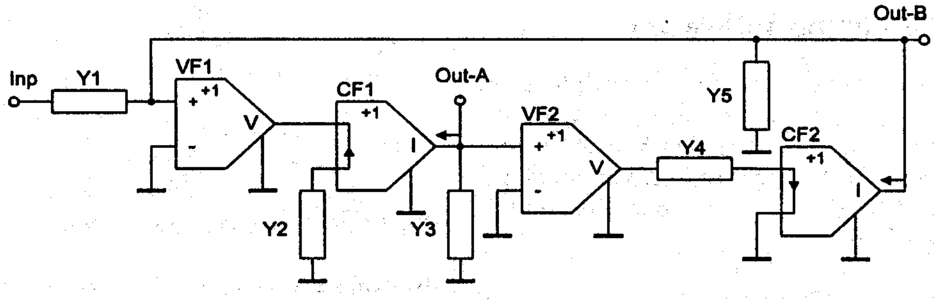

Fig. 6 Structure B4F-A of the biquad, using four followers VF and CF+.

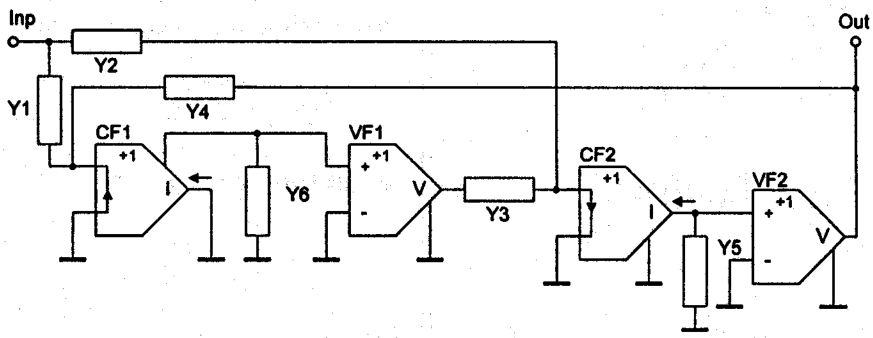

Fig. 7 Structure B4F-B of the biquad with four followers.

$$K_A(s) = \frac{V_{out}^{(A)}}{V_{in}} = \frac{-Y_1Y_3}{Y_1Y_2 + Y_2Y_4 + Y_3Y_4}, \quad (12)$$

$$K_B(s) = \frac{V_{out}^{(B)}}{V_{in}} = \frac{Y_1Y_2}{Y_1Y_2 + Y_2Y_4 + Y_3Y_4}. \quad (13)$$

Note that other lower number of the followers can not be good utilised in today practical implementations using the transimpedance amplifiers. However the both given structures B4F-B and B4F-A employ two transimpedance amplifiers only.

*Tab. 1: Variants of the filter implementation using the structure **B4F-A** (Fig. 6)*

Variant	Admittance					Output	
	Y_1	Y_2	Y_3	Y_4	Y_5	A	B
B4FA-1	sC_1	R_2^{-1}	sC_3	R_4^{-1}	R_5^{-1}	BP	HP
B4FA-2	R_1^{-1}	R_2^{-1}	sC_3	R_4^{-1}	sC_5	LP	BP
B4FA-3	R_1^{-1}	sC_2	R_3^{-1}	sC_4	sC_5	BP	LP
B4FA-4	sC_1	sC_2	R_3^{-1}	sC_4	R_5^{-1}	HP	BP

*Tab. 2: Variants of the filter implementation using the structure **B4F-B** (Fig. 7).*

Variant	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Output
B4FB-1	R_1^{-1}	-	sC_3	R_4^{-1}	R_5^{-1}	$sC_6+ R_6^{-1}$	LP
B4FB-2	-	R_2^{-1}	sC_3	R_4^{-1}	R_5^{-1}	$sC_6+ R_6^{-1}$	BP
B4FB-3	-	sC_2	sC_3	R_4^{-1}	R_5^{-1}	$sC_6+ R_6^{-1}$	HP

*Tab. 3: Variants of the filter implementation using the structure **B3F** (Fig. 8).*

Variant	Y_1	Y_2	Y_3	Y_4	Out-A	Out-B
B3F-1	sC_1	sC_2	R_3^{-1}	R_4^{-1}	BP	HP
B3F-2	R_1^{-1}	R_2^{-1}	sC_3	sC_4	BP	LP

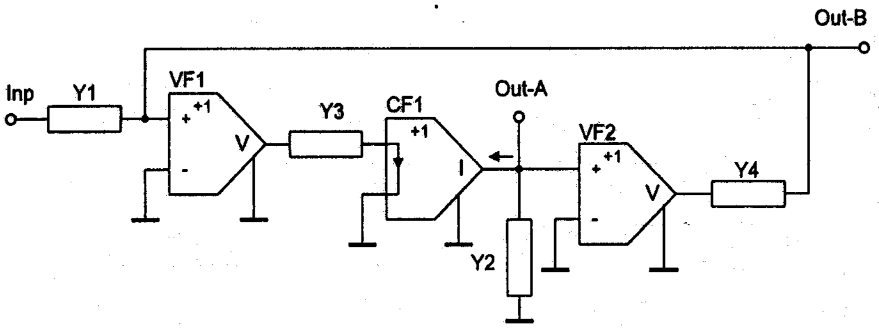

Fig. 8 Structure B3F3 of the biquad with three followers.

5. ARC filters using given structures

The particular choice of the admittance's Y_i in the structure **B4F-A** (Fig. 6), can be easily determine by the denominator in the eq. (7) or (8), to give the 2nd order polynomial of the variable s. Note that, we assume for each Y the R or the C, as a single component only. All suitable combinations in four particular variants are given in the Tab. 1. Similarly for the structures **B4F-B** and **B3F** suitable variants are given in the Tab. 2 and Tab. 3.

Nevertheless we pay more our attention on the **B4F-A.** There the variants (Tab. 1) are not practically equivalent, due to the influence of the parasitic driving impedances of the real followers, specially the input resistance (R_x) of the current followers (CF_1 and CF_2). Better is if the parasitic R_x interacts as simple sum with the resistors R_2 and R_3, what is in the B4FA-1 and B4FA-2. In this case the basic filter parameters (ω_0, Q) are charged with small errors only. In other configurations (B4FA-3 and B4FA-4) the resistances R_x interact with the capacitors C_2 and C_3 and these time constants influence more the filter parameters.

6. Modification for current conveyors

The ARC structures given above can be fairly modified for the implementation using the current conveyors CC II. An example of this modification of the structure B4F-A (Fig. 6) is obtained by changing the orientation of the input port and along with the sign of the parameter F = - 1 of the CF 2 (Fig. 6). Then the practicable implementation using two CC II+/- is shown in Fig. 9. The circuit was symbolical analysed by SNAP to obtain the same results (7) and (8) given above.

7. Simulation results

To illustrate a design of the biquad we take the variant B4FA-2 (Tab. 1). There the transfer function (8) becomes in this form

$$K_B(s) = \frac{sC_3G_1}{s^2C_5C_3 + sC_3G_1 + G_2G_4}, \qquad (14)$$

From the eq. (14), the natural frequency (15) and the quality factor of the poles (16) are given as follows

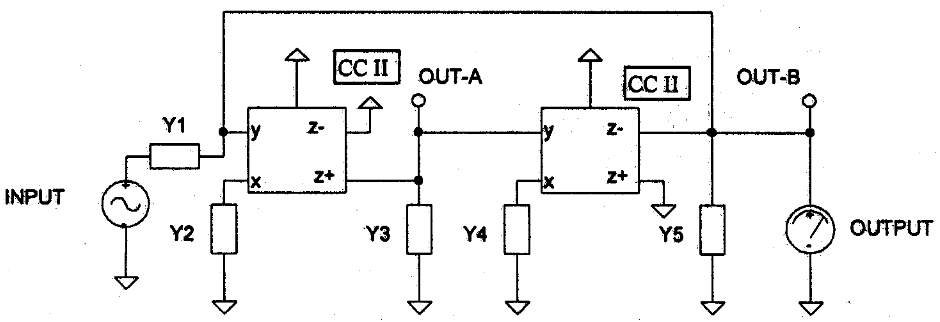

Fig. 9 Implementation of the structure B4F-A (Fig. 6) using current conveyors CC II+/- (Simulation in SNAP)

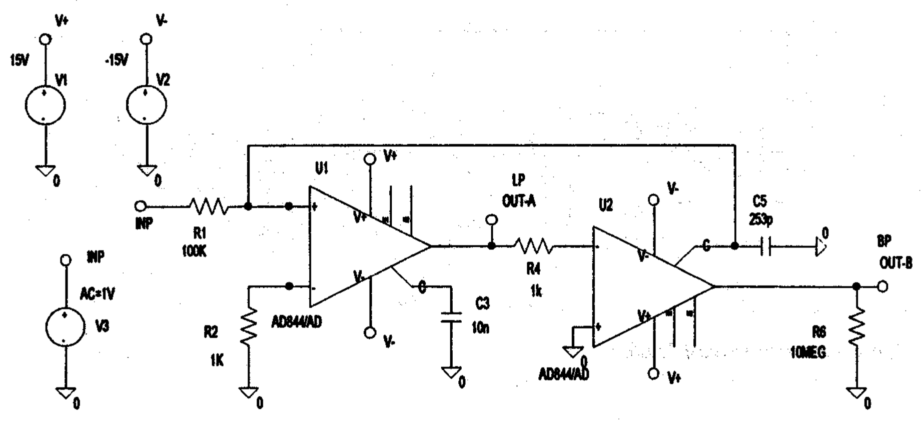

Fig. 10 Implementation of the structure B4FA (Fig. 6), the variant B4FA-2 (Tab. 1), using the TIOA (AD 844). (Simulation in PSpice)

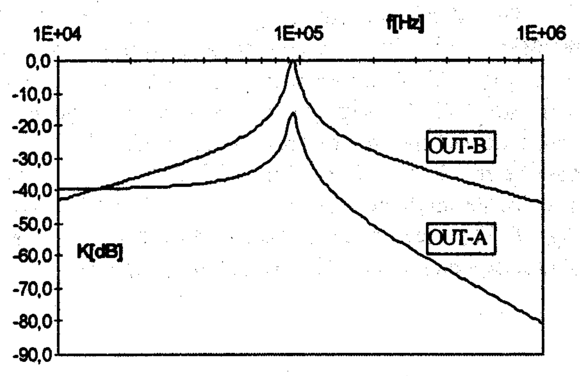

Fig. 11 Magnitude responses of the filter B4FA from Fig. 10.

$$\omega_o = \frac{1}{\sqrt{C_5 R_2 C_3 R_4}} , \qquad (15)$$

$$Q = \frac{R_1}{\sqrt{R_2 R_4}} \sqrt{\frac{C_5}{C_3}} . \qquad (16)$$

The given equations (15) and (16) have been used for the design of the ARC filter with this specification:
2nd order BP, $f_o = 100\ kHz$, $Q = 16$.

The designed circuit B4FA-2 (Fig. 6) has the following values:

$R_1 = 100\ k\Omega$, $R_2 = R_4 = 1\ k\Omega$,
$C_3 = 10\ nF$, $C_5 = 253\ pF$.

This filter was modified for the transimpedance operational amplifiers AD 844 (Fig. 10) and simulated with the PSpice, using professional macro models. The resulting magnitude responses of the both outputs (Out-A, Out-B) are in Fig. 11. One can see, that there is a wide frequency range without distortion. So the simulations are well confirming the theoretical assumptions.

Furthermore note that the all sensitivities of the given circuits are small

$$S_Y^{\omega_o} < 1 , \qquad S_Y^Q < 1 . \qquad (17)$$

8. Filters in current mode

If the signal is required as the current to be processed, then the adjoint transformation from [3] can be used, to obtain the other adjoint structures in the current mode (CM). Illustrating this method, the biquadratic structure of the B3B (Fig. 8) is taken and transformed in the adjoint circuit in the CM, as shown in Fig. 12. There the current gain has the same symbolical form as the voltage one, given above, namely (12) and (13).

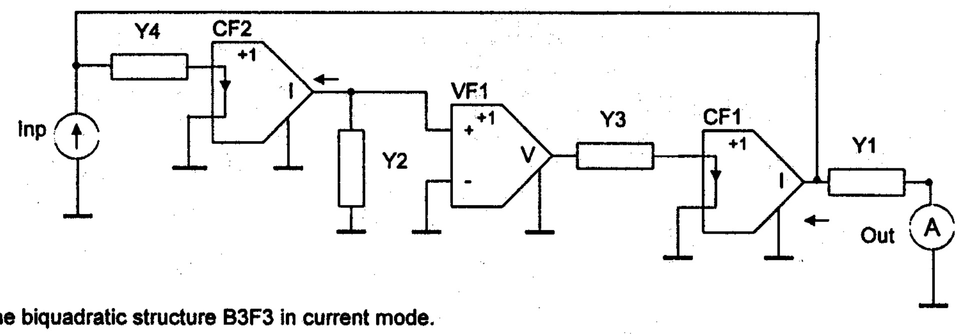

Fig. 12 The biquadratic structure B3F3 in current mode.

9. Conclusion

The given structures of the biquadratic ARC filter using the non-inverting voltage followers and the dual positive current followers is evidently right choice for high frequency applications. These filters can be practically implemented by the two commercially available transimpedance operational amplifiers AD 844. The simulated results have confirmed this conclusion.

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Tomáš DOSTÁL was born in Brno, in 1943. He received the CSc. (Ph.D) and DrSc. degree in electrical engineering from the Technical University Brno in 1976 and 1989 respectively. From 1973 to 1978, and from 1980 to 1984, was with Military Academy Brno, from 1978 to 1980 with Military Technical College Baghdad. Since 1984 he has been with the Technical University Brno, where he is now Professor of Radioelectronics. His present interests are in the circuit theory, filters, switched capacitor networks and circuits in current mode.

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