PRINCIPLES OF ARC FILTER SYNTHESIS INVOLVING CURRENT AND VOLTAGE CONVEYORS

Ing. Radek ŠPONAR, Doctoral Degree Programme (1)
Dept. of Telecommunications, FEEC, BUT
E-mail: xspona00@stud.feec.vutbr.cz

Supervised by: Prof. Kamil Vrba

ABSTRACT

The article gives a summary of several network principles of active RC filter design with current and voltage conveyor implementation. The first and the second canonical form of general filter integrator-based structures are presented and second-order voltage- and current-mode multifunction filters are explained. The actual filter design is concentrated on the UCC device usage because of its real fabrication.

1 CURRENT AND VOLTAGE CONVEYOR DEFINITION

Conveyors are complex analogue function blocks comprising Current Controlled Current Sources (CCCS) and Voltage Controlled Voltage Sources (VCVS). Owing to the historical development, there are several kinds of current and voltage conveyors (CC, VC), which differ in number of ports and transfer coefficient values ([1] - [5]).

Each conveyor as the special type of immittance converter [6], [7] has three types of grounded ports: X, Y and Z with their numbers N_X, N_Y, N_Z respectively. Total count of ports equals to N. Voltage and current transfer equations in agreement with [6] - [9] are expressed as

$$\text{CC}: \quad V_X = \sum_{j=1}^{N_Y} \alpha_j V_{Y,j} + \sum_{k=1}^{N_Z} \delta_k V_{Z,k},\ I_{Y,j[1,N_Y]} = \beta_j I_X,\ I_{Z,k[1,N_Z]} = \gamma_k I_X, \quad (1)$$

$$\text{VC}: \quad I_X = \sum_{j=1}^{N_Y} \alpha_j I_{Y,j} + \sum_{k=1}^{N_Z} \delta_k I_{Z,k},\ V_{Y,j[1,N_Y]} = \beta_j V_X,\ V_{Z,k[1,N_Z]} = \gamma_k V_X. \quad (2)$$

Thus the particular conveyor is defined by its *form* (CC, VC), *total number of ports* (N), *order* (N_X), *type* (N_Y) and *set of coefficients* (α, β, γ, δ). The β coefficient determines the conveyor generation ($\beta = +1$, first; $\beta = 0$, second; $\beta = -1$, third). The α coefficient describes input voltage (CC) or current (VC) transfer ($\alpha = +1$, non-inverting; $\alpha = -1$, inverting) and γ coefficient describes output current (CC) or voltage (VC) transfer ($\gamma = +1$, positive; $\gamma = -1$, negative). The δ coefficient is usually equal to zero. The minimum three-port conveyor configuration shown in Fig. 1 can be freely expanded by adding more Y and Z ports while $N_Z \geq N_X$ and $N_Y \geq N_X$. The number of X ports N_X mostly matches one.

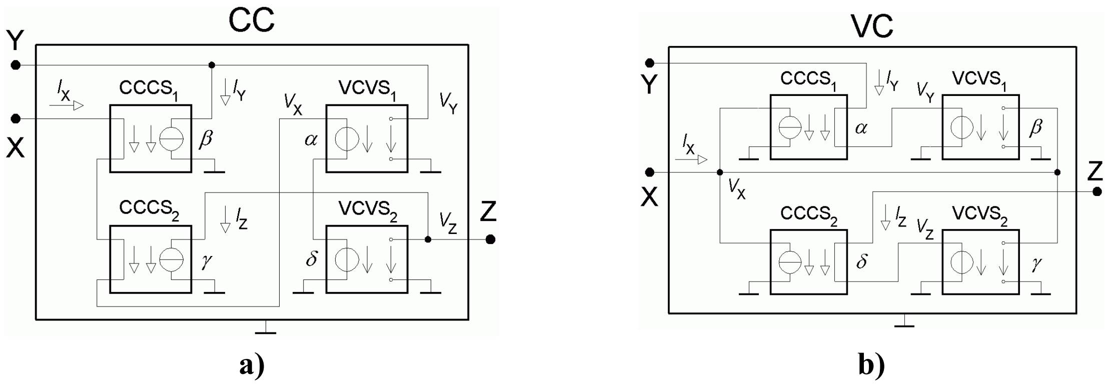


Fig. 1: *Internal three-port conveyor configuration: a) current conveyor, b) voltage conveyor*

2 UNIVERSAL CURRENT AND VOLTAGE CONVEYOR

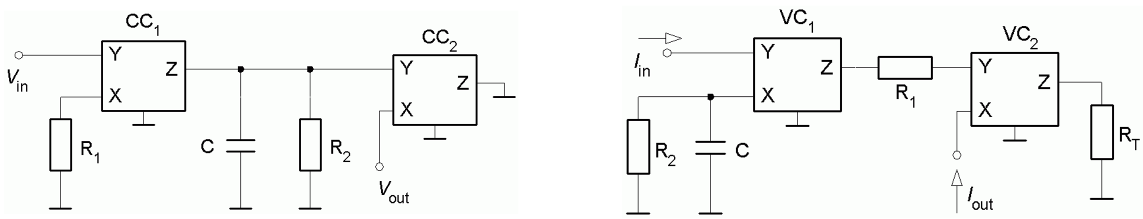
The implementation of the Universal Current Conveyor as CC(8,1,3) [10], [11] was introduced and the real device is being tested at present. By analogy the Universal Voltage Conveyor VC(8,1,3) can be determined. Their transfer equations are

$$\mathrm{CC:}\quad V_{\mathrm{X}} = V_{\mathrm{Y1+}} - V_{\mathrm{Y2-}} + V_{\mathrm{Y3+}},\ I_{\mathrm{Z1+}} = I_{\mathrm{Z2+}} = I_{\mathrm{X}},\ I_{\mathrm{Z1-}} = I_{\mathrm{Z2-}} = -I_{\mathrm{X}}, \quad (3)$$

$$\mathrm{VC:}\quad I_{\mathrm{X}} = I_{\mathrm{Y1+}} - I_{\mathrm{Y2-}} + I_{\mathrm{Y3+}},\ V_{\mathrm{Z1+}} = V_{\mathrm{Z2+}} = V_{\mathrm{X}},\ V_{\mathrm{Z1-}} = V_{\mathrm{Z2-}} = -V_{\mathrm{X}}. \quad (4)$$

3 BASIC FILTER PRINCIPLES

Elementary first-order filter structures as losing integrators are presented in Fig. 2.



a) $$K_{\mathrm{V}}(s) = \frac{\alpha_1 \alpha_2 \gamma_1}{sR_1 C + R_1/R_2 - \gamma_1 \delta_1} \quad (5)$$ **b)** $$K_{\mathrm{I}}(s) = \frac{-\alpha_1 \alpha_2 \gamma_1}{sR_1 C + R_1/R_2 - \gamma_1 \delta_1} \quad (6)$$

Fig. 2: *a) Voltage integrator using CC, b) current integrator using VC*

The voltage integrator comprises high input impedance and low output impedance whereas the current integrator contains low input impedance and high output impedance. Their voltage and current transfer functions are added below. Mostly the δ coefficient is equal to zero and in the case of omitting the resistor R_2 we obtain lossless integrators. The value of the β coefficient is irrelevant therefore we can use CCII+/– and VCII+/– or ICCII+/– and IVCII+/–.

4 MULTIFUNCTION FILTER STRUCTURES

There are two dual universal filter constructions independent of the operation mode (voltage, current, mixed). The first and the second canonical form [12]) express general integrator-based filter structures (Fig. 3) which can be used as multifunction high-order single-input and single-output filters.

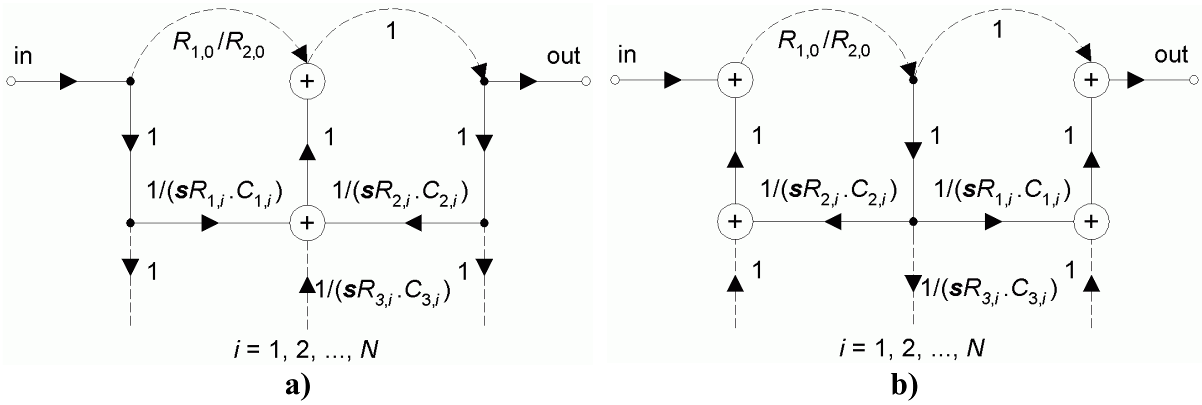


Fig. 3: *General first-order integrator-based filter elements as: a) the first canonical form, b) the second canonical form*

Disconnecting the dashed lines and joining the similar filter elements below the presented ones, it is feasible to construct the high-order (*N*th order) filter architectures. Designing the ARC filters based on current and voltage conveyor implementation, it is useful to integrate grounded resistors and capacitors where possible as in Fig. 2.

The extended second canonical form of second-order voltage mode filter realized by the current conveyors denoted as AMIS 0349 UCCX [11] is shown in Fig. 4. The voltage transfer function is

$$K_\mathrm{V}(s)=\frac{N(s)}{D(s)}=K_0\,\frac{s^2+s\dfrac{\omega_\mathrm{Z}}{Q_\mathrm{Z}}+\omega_\mathrm{Z}^2}{s^2+s\dfrac{\omega_\mathrm{P}}{Q_\mathrm{P}}+\omega_\mathrm{P}^2}=\frac{\overbrace{s^2\dfrac{R_3}{R_1}}^{N_2(s)}+\overbrace{s\dfrac{1}{C_2R_1}}^{N_1(s)}+\overbrace{\dfrac{1}{C_1R_1C_3R_2}}^{N_0(s)}}{s^2+s\dfrac{1}{C_4R_1}+\dfrac{1}{C_1R_1C_5R_2}}. \tag{7}$$

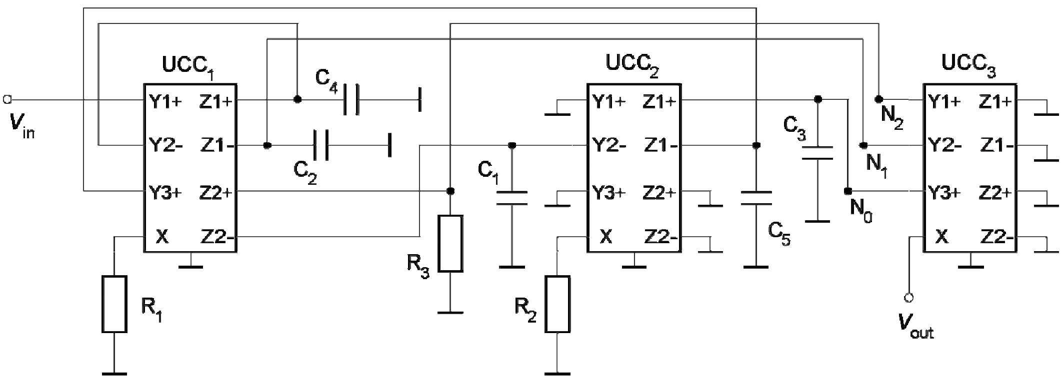


Fig. 4: *Second-order voltage-mode multifunction filter using the UCC device*

Grounding the N_2, N_1 or N_0 node, the term $N_2(s)$, $N_1(s)$ or $N_0(s)$ in (7) disappears respectively. According to the adjoint voltage-current mode transformation [13], there is the way of changing the operation mode of the filter shown in Fig. 4. Due to the slight non-symmetry of the UCC device (3 high-impedance input voltage ports, 4 high-impedance output current ports), the infinity frequency high-pass gain must be less or equal to one as stated in the current transformation function

$$K_{\mathrm{I}}(s)=\frac{N(s)}{D(s)}=\frac{\overbrace{s^2\frac{R_3}{R_1}}^{N_2(s)}+\overbrace{s\frac{1}{C_2R_1}}^{N_1(s)}+\overbrace{\frac{1}{C_1R_1C_3R_2}}^{N_0(s)}}{s^2\left(1+\underbrace{\frac{R_3}{R_1}}_{D_2(s)}\right)+s\frac{1}{C_4R_1}+\frac{1}{C_1R_1C_5R_2}}. \qquad (8)$$

The multifunctionality of proposed first canonical form of second-order current mode filter is provided again. When the N_2, N_1 or N_0 node is grounded, the term $N_2(s)$, $N_1(s)$ or $N_0(s)$ in (8) disappears respectively. Moreover the term $D_2(s)$ equals to zero when grounding the N_2 node. The filter structure is presented in Fig. 5.

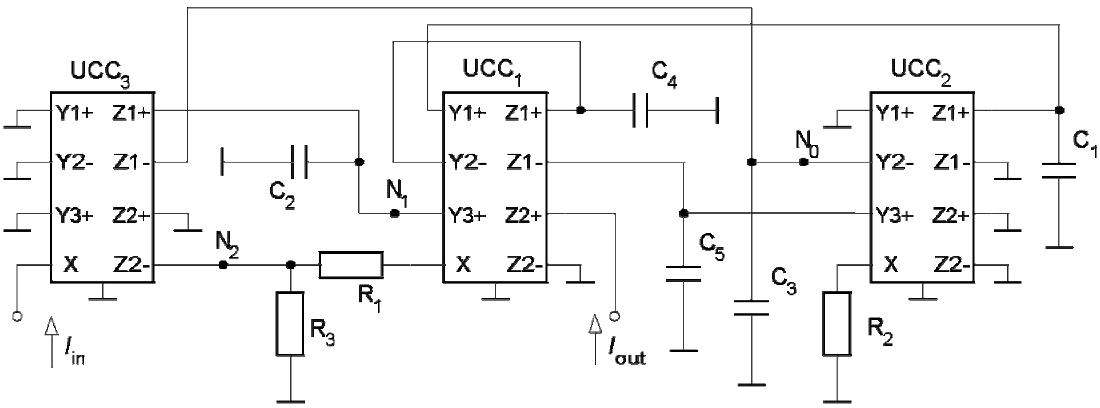


Fig. 5: *Second-order current-mode multifunction filter using the UCC device*

The circuits in Fig. 4, 5 utilized the basic integrator CC structure displayed in Fig. 2. Due to the UCC_3, the operation-mode modification into the (non-)inverting mixed-modes (multiple-output V/C mode in Fig. 4 or multiple-input C/V mode in Fig. 5) is allowed.

5 CONCLUSION

Nowadays the high-frequency ARC filter design is mainly focused on the complex analogue function block implementation. Variety of current and voltage conveyors have been presented to achieve new active circuit prototypes working in voltage-, current- and mixed-mode. The paper shows several principles how to obtain a multifunction filter structure providing the second- or higher order transfer function.

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