REALIZATION OF NTH-ORDER VOLTAGE TRANSFER FUNCTION USING CURRENT CONVEYORS CCII

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Abstract:

A universal method for the realization of arbitrary voltage transfer function in canonic form is presented. A voltage-controlled current-source using a plus-type second-generation current conveyor is here applied as the basic building element. Filters designed according to this method have a high input impedance and low sensitivity to variations of circuit parameters. All passive elements are grounded.

Keywords:

circuit theory, current conveyors, active filters

Our aim is to realize a two-port , the voltage transfer function of which

$$T(s) = P(s)/Q(s) \tag{1}$$

has the simplest possible form. Here, $P(s)$ and $Q(s)$ are polynomials of arbitrary order. Let us denote the maximal polynomial order as n.

We can use a voltage-controlled current-source (VCCS) for the above purpose. The realization of a grounded VCCS using current conveyor CCII+ is shown in Fig. 1, where the transadmittance of the source is Y_{2k+1}. Second-generation conveyors CCII were described in [1]. Loading the above mentioned VCCS in Fig. 1 by a passive one-port element with the admittance Y_{2k+2}, we obtain an elementary two-port network with a simple voltage transfer function (VTF):

$$T = \frac{V_2}{V_1} = \frac{Y_{2k+1}}{Y_{2k+2}} .$$

If we connect n loaded VCCS's according to Fig. 1 in cascade (see the middle part of Fig. 2), we get a two-port network with the following VTF

$$T = \frac{V_2}{V_1} = \prod_{k=0}^{n-1} \frac{Y_{2k+1}}{Y_{2k+2}} . \tag{2}$$

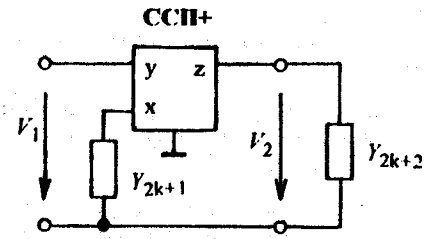


Fig. 1 Loaded voltage-controlled current-source using CCII+

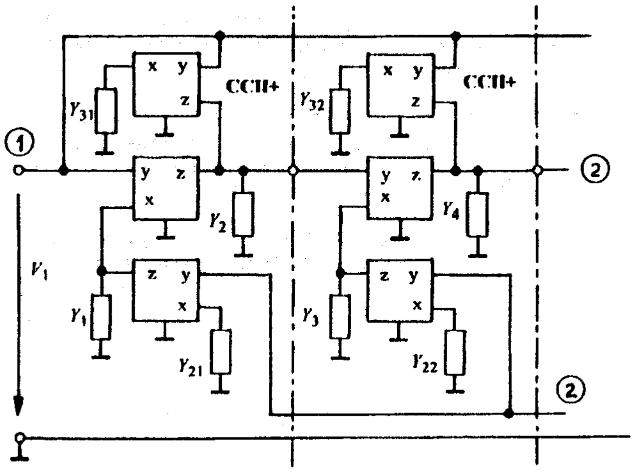


Fig. 2 Interconnection of stages for the generalized two-port network design

The numerator and also the denominator of eqn. (2) can be expanded by introducing suitable feedbacks.

As an example, let us consider the cascade of 4 elementary two-ports (n=4). The VTF of this two-port according to eqn. (2) is

$$T = \frac{Y_1 Y_3 Y_5 Y_7}{Y_2 Y_4 Y_6 Y_8} . \tag{3}$$

Let us denote the live terminal of the input port by number **1** and that of the ouput port by number **2**. We can enlarge the number of *denominator* terms in eqn. (3) by connecting a feedback between the output terminal **2** and the x-terminal of any CCII+ in the basic cascade using an unloaded VCCS (see Fig. 3a) . Each realized feedback path adds one new term to the basic term $Y_2Y_4Y_6Y_8$ in denominator. Using all possibilities as shown in the lower part of Fig. 4, we get following terms in denominator of eqn. (3)

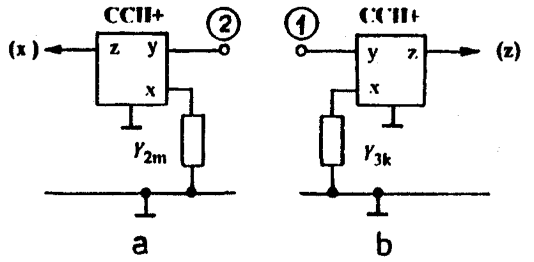


Fig. 3 a) Feedback element for denominator expansion, b) Coupling element for numerator expansion

$$Q(s) = Y_2Y_4Y_6Y_8 + Y_2Y_4Y_6Y_{24} + Y_2Y_4Y_{23}Y_7 + \\ +Y_2Y_{22}Y_7Y_5 + Y_{21}Y_7Y_5Y_3 \; . \qquad (4)$$

Here, symbols Y_{21}, Y_{22}, Y_{23} and Y_{24} represent transadmittances of the coupling VCCS's.

The number of terms in the *numerator* of eqn. (3) increases when we realize a coupling path from the input port 1 to some or to all z-terminals of the basic cascade using simple VCCS's. If we use all possible connections as shown in the upper part of Fig. 4, we obtain

$$P(s) = Y_1Y_3Y_5Y_7 + Y_3Y_5Y_7Y_{31} + Y_5Y_7Y_{32}Y_2 + \\ +Y_7Y_{33}Y_2Y_4 + Y_{34}Y_2Y_4Y_6 \; . \qquad (5)$$

The term sign in the numerator can be changed if we use the conveyor CCII- instead of CCII+ as a forward coupling element.

The use of all coupling elements for the VTF realization is not necessary. In our case, we can omit VCCS's with transadmittances Y_{31}, Y_{33}, Y_{24} and Y_{22}. Then the generalized VTF of the simplified network has the following form

$$T(s) = \frac{Y_1Y_3Y_5Y_7 + Y_5Y_7Y_{32}Y_2 + Y_{34}Y_2Y_4Y_6}{Y_2Y_4Y_6Y_8 + Y_2Y_4Y_{23}Y_7 + Y_{21}Y_7Y_5Y_3} \; . \qquad (6)$$

As an example, we will show the realization of a 4th-order lowpass filter (LPF). First, we delete the coupling VCCS's with Y_{32} and Y_{34}. The remaining term in the numerator is $Y_1Y_3Y_5Y_7$. Then we choose: $Y_1=G_1$, $Y_2=sC_1$, $Y_3=G_2$, $Y_4=sC_2$, $Y_5=G_3$, $Y_6=sC_3$, $Y_7=G_4$, $Y_8=sC_4+G_5$, $Y_{23}=G_6$ and $Y_{21}=sC_5+G_7$. The corresponding circuit scheme is shown in Fig.5. This network is simpler than the one recently published in [2]. The VTF of our network is

$$T(s) = V_2/V_1 = G_1G_2G_3G_4 \;/\; (s^4C_1C_2C_3C_4 + \\ s^3C_1C_2C_3G_5 + s^2C_1C_2G_4G_6 + sC_5G_2G_3G_4 + \\ +G_2G_3G_4G_7) \; . \qquad (7)$$

We can modify the scheme in Fig. 5 when we apply: $Y_8=sC_4$, $Y_{21}=sC_5+G_5$ and $Y_{23}=sC_6+G_6$.

As a further example, let us consider only two basic stages connected in cascade with necessary coupling elements (see Fig. 6a). The generalized VTF is in this case

$$T(s) = \frac{Y_1Y_3 + Y_{32}Y_2}{Y_2Y_4 + Y_{21}Y_3} \; . \qquad (8)$$

Deleting the VCCS with Y_{32} and choosing e.g. $Y_1=G_1$, $Y_2=sC_1$, $Y_3=G_3$, $Y_4=sC_2+G_2$ and $Y_{21}=G_4$ we get a second-order *lowpass filter* (biquad) with the following voltage ratio

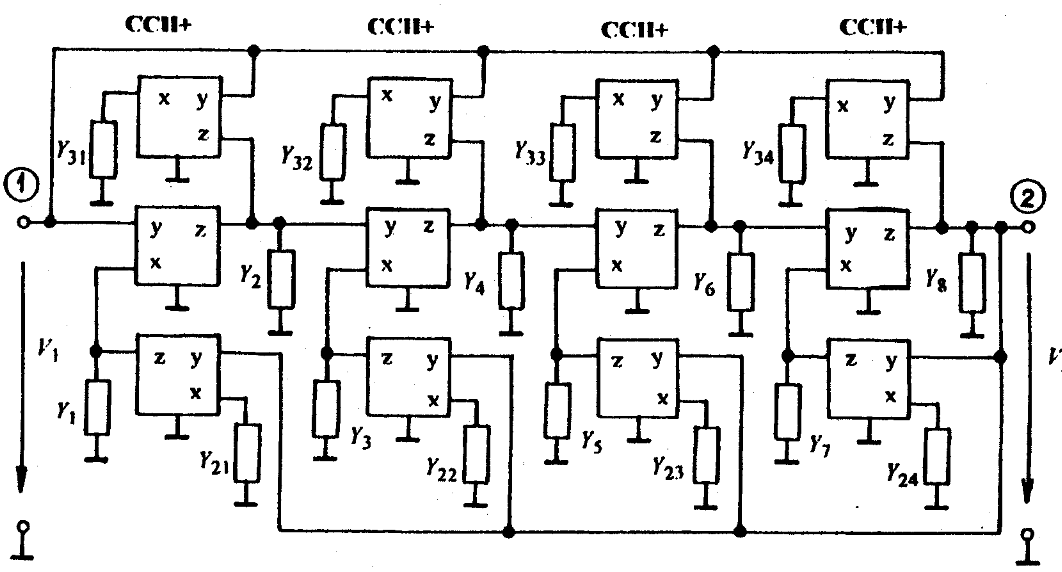


Fig. 4 Generalized two-port network for realization of fourth-order voltage transfer function

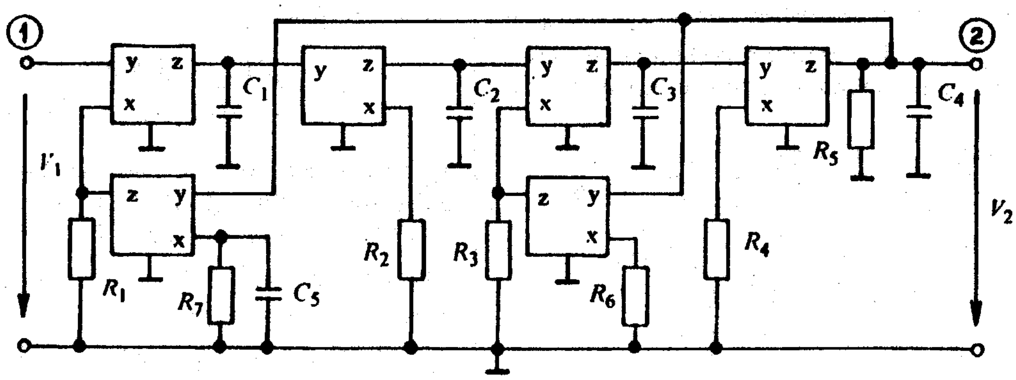


Fig. 5 Fourth-order lowpass filter with CCII+

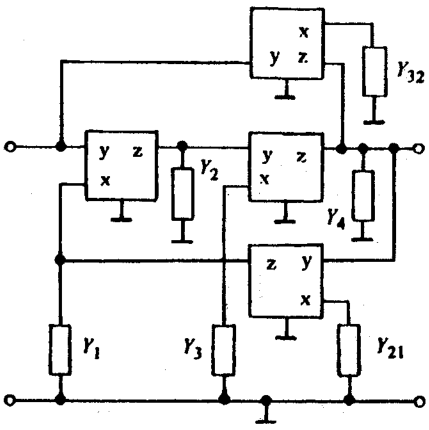
$$T(s) = \frac{V_2}{V_1} = \frac{G_1 G_3}{s^2 C_1 C_2 + s C_1 G_2 + G_3 G_4} \quad . \qquad (9)$$

A *highpass filter* is produced by replacing resistors by capacitors and vice versa.

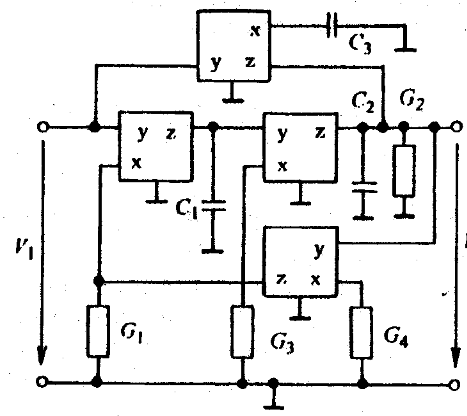
Choosing $Y_1=0$, $Y_2=sC_1$, $Y_3=G_3$, $Y_4=sC_2+G_2$, $Y_{32}=G_1$ and $Y_{21}=G_4$ we obtain a *bandpass filter* having the following VTF

$$T(s) = \frac{V_2}{V_1} = \frac{s C_1 G_1}{s^2 C_1 C_2 + s C_1 G_2 + G_3 G_4} \quad . \qquad (10)$$

From eqn. (10) it results that the quality factor Q of the network can be controlled by conductance G_2 independently of resonance angular frequency ω_0, which is independently controllable by the value of G_3 or G_4.



a



b

Fig. 6 a) Generalized two-port network for biquads,
b) notch filter using CCII+

Finally, choosing $Y_1=G_1$, $Y_2=sC_1$, $Y_3=G_3$, $Y_4=sC_2+G_2$, $Y_{32}=sC_3$ and $Y_{21}=G_4$ the network represents a *notch filter* shown in Fig. 6b. Its VTF is

$$T(s) = \frac{V_2(s)}{V_1(s)} = \frac{s^2 C_1 C_3 + G_1 G_3}{s^2 C_1 C_2 + s C_1 G_2 + G_3 G_4} \quad . \qquad (11)$$

The advantage of the network described is: 1) Simple realization of an arbitrary VTF, 2) High input impedance of the two-port, 3) All passive elements are grounded, 4) Low sensitivity to variations of network parameters.

The notch filter of the structure from Fig. 6b can be implemented by AD 844 transimpedance opamps, namely the first part of these can really simulate CCII+ there. Taking a design variant of the values $C_1= C_2= C_3= C$ and $R_1= R_3= R_4= R$, the parameters of the notch filter are given by simple formulas

$$\omega_0 = \omega_r = \frac{1}{RC} \, , \qquad Q = \frac{R_2}{R} \, . \qquad (12)$$

Here ω_r denotes the rejection angular frequency.

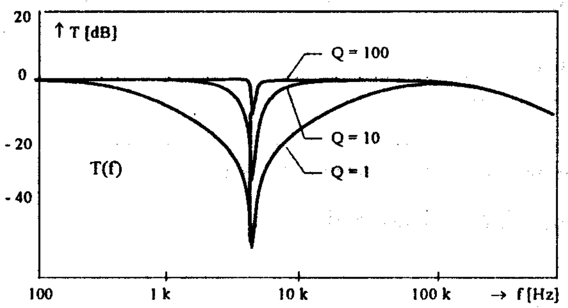


Fig. 7 Simulated frequency-magnitude response of a notch filter acc. to Fig. 6b

The circuit has been simulated using the PSPICE A/D program for the following specifications: f_0 = 5 kHz, Q =1, 10, 100. The passive component values are R = 3.183 kΩ, C =10 nF, and various values of R_2. The magnitude-frequency responses obtained are shown in Fig. 7. These confirm that Q-factor can be varied without affecting the value of ω_0 as mentioned above. A distortion given in Fig. 7 in higher frequency range is an effect of parasitic performances of the real active components. Good agreement between these simulated results and the given theory is apparent.

References

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Josef ČAJKA was born in Vracov, Czech republic, in 1919. He received the M.E. degree in electrical engineering from VUT Brno in 1946, the Ph.D degree from Military Academy Brno in 1961 and the DrSc. Degree from the Technical University Brno in 1981. He was researcher with the Bat'a Corp. In Zlín 1947-1951, then he joined the Military Academy Brno and in 1972 the Technical University Brno. Since 1984, he has been Professor emeritus. His research and pedagogical interest was the Circuit theory.

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