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

Josef ČAJKA, Tomáš DOSTÁL and Kamil VRBA
Technical University Brno
Purkyňova 118, CZ-612 00 Brno
Czech Republic

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

\[ T(s) = \frac{P(s)}{Q(s)} \]  \hspace{1cm} (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):

\[ T = \frac{V_2}{V_1} = \frac{Y_{2k+1}}{Y_{2k+2}} . \]  \hspace{1cm} (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

\[ T = \frac{V_2}{V_1} = \prod_{k=0}^{n-1} \frac{Y_{2k+1}}{Y_{2k+2}} . \]  \hspace{1cm} (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

\[ T = \frac{Y_{2}Y_{4}Y_{6}}{Y_{1}Y_{2}Y_{4}} . \]  \hspace{1cm} (3)

Let us denote the live terminal of the input port by number 1 and that of the output 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 $Y_2 Y_4 Y_6 Y_8$ in denominator. Using all possibilities as shown in the lower part of Fig. 4, we get the following terms in denominator of eqn. (3)

\[
T(s) = \frac{Y_1 Y_2 Y_3 Y_4 + Y_2 Y_4 Y_6 Y_8 + Y_2 Y_4 Y_23 Y_7 +}{Y_2 Y_22 Y_25 Y_5 + Y_21 Y_7 Y_5 Y_3}.
\]

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 $Y_1 Y_3 Y_5 Y_7$. Then we choose: $Y_1 = G_1$, $Y_2 = s C_1$, $Y_3 = G_2$, $Y_4 = s C_2$, $Y_5 = G_3$, $Y_6 = s C_3$, $Y_7 = G_4$, $Y_8 = s C_4 + G_5$, $Y_{23} = G_6$ and $Y_{21} = s C_5 + G_7$. 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

\[
T(s) = \frac{Y_2 Y_1}{s^4 C_1 C_2 C_4} + G_1 G_2 G_3 G_4 + (s^4 C_1 C_2 C_4 + s^3 C_1 C_2 C_3 G_5 + s^2 C_1 C_2 G_4 G_6 + s C_5 G_2 G_3 G_4 + G_2 G_3 G_4 G_7)
\]

Here, symbols $Y_{31}$, $Y_{22}$, $Y_{23}$ 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

\[
Q(s) = Y_1 Y_3 Y_5 Y_7 + Y_3 Y_5 Y_7 Y_{31} + Y_5 Y_7 Y_{32} Y_2 +
\]

\[
+Y_7 Y_{33} Y_2 Y_4 + Y_3 Y_4 Y_6.
\]

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

\[
T(s) = \frac{Y_1 Y_2 Y_3 Y_4 + Y_2 Y_4 Y_6 Y_8 + Y_2 Y_4 Y_23 Y_7 +}{Y_2 Y_22 Y_25 Y_5 + Y_21 Y_7 Y_5 Y_3}.
\]

We can modify the scheme in Fig. 5 when we apply: $Y_8 = s C_4$, $Y_{21} = s C_5 + G_5$ and $Y_{23} = s C_6 + G_6$.

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

\[
T(s) = \frac{Y_1 Y_3 + Y_2 Y_2}{Y_1 Y_4 + Y_2 Y_5}.
\]

Deleting the VCCS with $Y_{32}$ and choosing e.g. $Y_1 = G_1$, $Y_2 = s C_1$, $Y_3 = G_3$, $Y_4 = s C_2 + G_2$ 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+

\[ T(s) = \frac{V_2}{V_1} = \frac{G_2G_3}{s^2C_1C_2 + sC_2G_2 + G_2G_4} \]  \hspace{1cm} (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

\[ T(s) = \frac{V_2}{V_1} = \frac{sC_1G_1}{s^2C_1C_2 + sC_2G_2 + G_2G_4} \]  \hspace{1cm} (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 \( \omega_0 \), which is independently controllable by the value of \( G_3 \) or \( G_4 \).

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

\[ T(s) = \frac{V_2(s)}{V_1(s)} = \frac{s^2C_1C_2 + G_2G_3}{s^2C_1C_2 + sC_2G_2 + G_2G_4} \]  \hspace{1cm} (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

\[ \omega_0 = \omega_r = \frac{1}{RC}, \quad Q = \frac{R_2}{R}. \]  \hspace{1cm} (12)

Here \( \omega_r \) denotes the rejection angular frequency.
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 $\omega_0$ 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


About authors...

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 Ba'a Corp. in Zlin 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.

Tomáš DOSTÁL was born in Brno, in 1943. He received the CSc. 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.

Kamil VRBA was born in Slavíkovice, Czech Republic, in 1949. He received the M.E. degree in electrical engineering in 1972 and the Ph.D. degree in 1977, both from Technical University Brno. He joined the Institute of Telecommunications at the Faculty of Electrical Engineering and Computer Science of the TU in Brno. His research work is concentrated to problems aimed to accuracy of analog circuits.