INT. J. ELECTRONICS, 1977, VOL. 42, NO. 1, 49–54

Two novel active RC canonic bandpass networks using the current conveyor

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Two new active RC bandpass resonators are given here. The active building block used is the second generation current conveyor. Both networks are canonic. The design equations are given, and the tuning procedure is discussed.

1. Introduction

The realization of all-pass transfer functions using the second generation current conveyor (CC II) as the active element was introduced by the author (Soliman 1973), and recently CC II was used to realize active RC oscillators (Soliman 1975).

In this paper two realizations of active RC canonic bandpass networks are given. It is seen that both filters are suitable for active integrated circuit production.

2. The first basic configuration

Figure 1 represents the basic structure, with CC II defined by its instantaneous port relations (Sedra and Smith 1970) :

$$\begin{bmatrix} i_b \\ v_a \\ i_c \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} v_b \\ i_a \\ v_c \end{bmatrix} \tag{1}$$

Analysis of the network, leads to the following voltage transfer function :

$$G(s) \equiv \frac{V_0}{V_i} = \frac{1}{\left(1 - \dfrac{R}{Z_{21}}\right) + \dfrac{2}{a}\left(1 - \dfrac{1}{T}\right)} \tag{2}$$

where $T(s)$ is the open circuit voltage transfer function of the passive RC network N, thus

$$T(s) = \frac{Z_{21}}{Z_{11}} \tag{3}$$

From (3) in (2), therefore,

$$G(s) = \frac{1}{\left(1 - \dfrac{R}{Z_{21}}\right) + \dfrac{2}{a}\left(1 - \dfrac{Z_{11}}{Z_{21}}\right)} \tag{4}$$

Two realizations of the passive RC network N are given here.

Received 1 June 1976.

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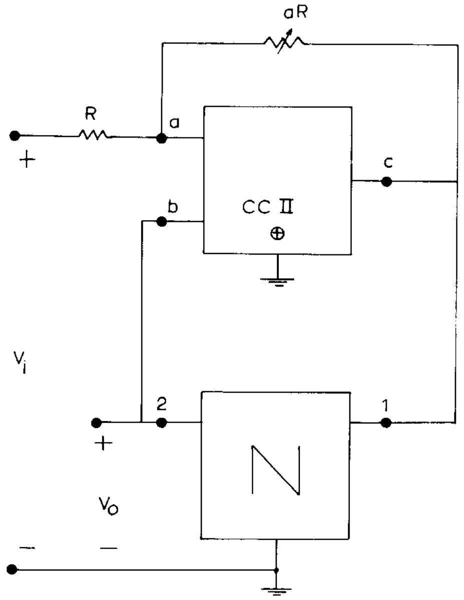
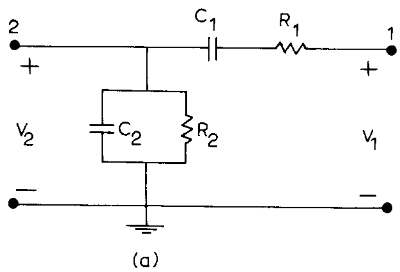


Figure 1. First basic realization of a bandpass network.



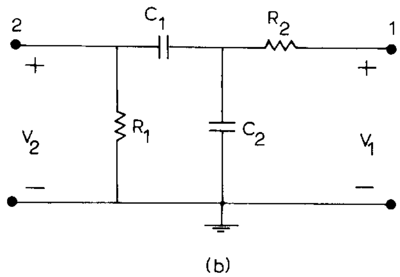


Figure 2. (*a*) Realization 1 of the passive RC network N. (*b*) Realization 2 of the passive RC network N.

2.1. *Realization* 1

Figure 2 (a) represents the network N. In this case

$$Z_{21}=\frac{R_2}{sC_2R_2+1} \tag{5}$$

$$Z_{11}=\frac{s^2C_1C_2R_1R_2+s(C_1R_1+C_2R_2+C_1R_2)+1}{sC_1(sC_2R_2+1)} \tag{6}$$

From eqns. (5) and (6) in (4), thus :

$$G(s)=\frac{-s\left(\dfrac{aC_1R_2}{2}\right)}{s^2C_1C_2R_2\left(R_1+\dfrac{aR}{2}\right)+s\left(C_1R_1+C_2R_2-\dfrac{a}{2}C_1R_2+\dfrac{a}{2}C_1R\right)+1} \tag{7}$$

which realizes an inverting bandpass transfer function of the form

$$G(s)=\frac{-K\omega_0 s}{s^2+\dfrac{\omega_0}{Q}s+\omega_0{}^2} \tag{8}$$

Comparing eqns. (7) and (8), thus :

$$\omega_0=\frac{1}{\sqrt{\left[C_1C_2R_2\left(R_1+\dfrac{aR}{2}\right)\right]}} \tag{9}$$

$$Q=\frac{\sqrt{\left[C_1C_2R_2\left(R_1+\dfrac{aR}{2}\right)\right]}}{C_1R_1+C_2R_2-\dfrac{a}{2}C_1R_2+\dfrac{a}{2}C_1R} \tag{10}$$

$$|G(j\omega_0)|\equiv KQ=\frac{\dfrac{aC_1R_2}{2}}{C_1R_1+C_2R_2-\dfrac{a}{2}C_1R_2+\dfrac{a}{2}C_1R} \tag{11}$$

The design equations

The design equations can be selected in a variety of ways. One possible way is to choose

$$C_1=C_2=C, \quad R_1=R_2=3R \tag{12}$$

In this case,

$$\omega_0=\frac{\sqrt{\frac{2}{3}}}{CR\sqrt{(6+a)}} \tag{13}$$

$$Q=\sqrt{\tfrac{3}{2}}\cdot\frac{\sqrt{(6+a)}}{6-a} \tag{14}$$

The parameter a should be less than 6 to ensure the stability of the network.

The design equations for $\omega_0 = 1$ are

$$R_1 = R_2 = 1, \quad R = \tfrac{1}{3}, \quad a \simeq 6 - \frac{3\sqrt{2}}{Q}, \quad \text{for } Q > 1 \tag{15}$$

$$C_1 = C_2 = \frac{\sqrt{6}}{\sqrt{(a+6)}} \approx \frac{1}{\sqrt{2}}, \quad \text{for } Q \gg 1 \tag{16}$$

The tuning procedure is to set Q to the desirable value by adjusting the resistor aR. Next the specified ω_0 is realized by tuning the two equal capacitors.

The Q sensitivity with respect to a can be obtained using (10), therefore

$$S_a^Q \equiv \frac{\partial Q}{\partial a} \cdot \frac{a}{Q} = \frac{a\dfrac{R}{2}}{2\left(R_1 + \dfrac{aR}{2}\right)} - \frac{a\dfrac{C_1}{2}(-R_2 + R)}{C_1R_1 + C_2R_2 - \dfrac{a}{2}C_1R_2 + \dfrac{a}{2}C_1R}$$

Using eqn. (12), thus for the case of interest,

$$S_a^Q = \tfrac{1}{4} + \sqrt{2}Q \simeq \sqrt{2}Q, \quad \text{for } Q > 1 \tag{17}$$

Another realization for the passive RC network N which will lead to a smaller Q sensitivity with respect to the parameter a, and a smaller spread in circuit components is given next.

2.2. *Realization* 2

Using the passive RC bandpass network shown in Fig. 2 (b) for N, thus :

$$Z_{21} = \frac{C_1R_1}{sC_1C_2R_1 + (C_1 + C_2)} \tag{18}$$

$$Z_{11} = \frac{s^2C_1C_2R_1R_2 + s(C_1R_1 + C_2R_2 + C_1R_2) + 1}{s^2C_1C_2R_1 + s(C_1 + C_2)} \tag{19}$$

From eqns. (18), (19) in (4), the transfer function of the active bandpass network is obtained as

$$G(s) = \frac{-asC_1R_1}{s^2C_1C_2R_1(2R_2 + aR) + s[2C_1R_2 + 2C_2R_2 + a(C_1 + C_2)R - aC_1R_1] + 2} \tag{20}$$

Comparing (20) and (8), thus :

$$\omega_0 = \sqrt{\left(\frac{2}{C_1C_2R_1(2R_2 + aR)}\right)} \tag{21}$$

$$Q = \frac{\sqrt{[2C_1C_2R_1(2R_2 + aR)]}}{2C_1R_2 + 2C_2R_2 + a(C_1 + C_2)R - aC_1R_1} \tag{22}$$

$$|G(j\omega_0)| = \frac{aC_1R_1}{2C_1R_2 + 2C_2R_2 + a(C_1 + C_2)R - aC_1R_1} \tag{23}$$

The design equations

The available degrees of freedom can be chosen in a variety of ways. To minimize the spread in circuit components and the Q sensitivity to the parameter a, the following choice is made. Choose

$$C_1 = C_2 = C, \quad R = R_2 = R_1/3 \tag{24}$$

In this case :

$$\omega_0 = \frac{1}{CR}\sqrt{\left(\frac{2}{3(2+a)}\right)}, \quad Q = \frac{\sqrt{6}(2+a)}{4-a} \tag{25}$$

The design equations for $\omega_0 = 1$ are

$$R = R_2 = \frac{R_1}{3} = 1, \quad C = \tfrac{1}{3} \tag{26}$$

$$a \simeq 4 - \frac{6}{Q}, \quad \text{for } Q > 1 \tag{27}$$

The Q sensitivity with respect to the parameter a is given by :

$$S_a^Q = \tfrac{1}{3} + \tfrac{2}{3}Q \simeq \tfrac{2}{3}Q, \quad \text{for } Q > 1 \tag{28}$$

Comparing with eqn. (17), it is seen that this realization is superior than realization 1.

3. The second basic configuration

Figure 3 represents the basic structure. By direct analysis, the open circuit voltage transfer function is found as

$$G(s) \equiv \frac{V_0}{V_i} = \frac{Y_1(Y_3 + Y_4)}{Y_1 Y_3 - 2Y_2 Y_4 - Y_3 Y_4} \tag{29}$$

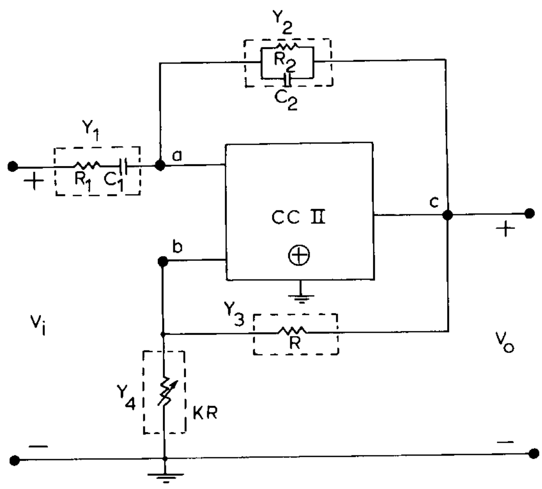


Figure 3. Second basic realization of a bandpass network.

A bandpass characteristics can be realized by choosing

$$Y_1 = \frac{sC_1}{1+sC_1R_1}, \quad Y_2 = \frac{1+sC_2R_2}{R_2}, \quad Y_3 = \frac{1}{R} \quad \text{and} \quad Y_4 = \frac{1}{KR} \tag{30}$$

In this case the transfer function is given by

$$G(s) = \frac{-\dfrac{sC_1R_2(K+1)}{2}}{s^2C_1C_2R_1R_2 + s\left[C_1R_1\left(1+\dfrac{R_2}{2R}\right) + C_2R_2 - \dfrac{KC_1R_2}{2}\right] + \left(1+\dfrac{R_2}{2R}\right)} \tag{31}$$

Comparing with eqn. (8), thus :

$$\omega_0 = \sqrt{\frac{1+\dfrac{R_2}{2R}}{C_1C_2R_1R_2}} \tag{32}$$

$$Q = \frac{\sqrt{\left[C_1C_2R_1R_2\left(1+\dfrac{R_2}{2R}\right)\right]}}{C_1R_1\left(1+\dfrac{R_2}{2R}\right) + C_2R_2 - \dfrac{KC_1R_2}{2}} \tag{33}$$

$$|G(j\omega_0)| = \frac{\dfrac{C_1R_2(K+1)}{2}}{C_1R_1\left(1+\dfrac{R_2}{2R}\right) + C_2R_2 - \dfrac{KC_1R_2}{2}} \tag{34}$$

The design equations

One possible set of design equations is as follows (for $\omega_0 = 1$) :

$$R_1 = R_2 = R = 1 \tag{35}$$

$$C = \sqrt{\tfrac{3}{2}} \tag{36}$$

$$K = 5 - \frac{\sqrt{6}}{Q} \tag{37}$$

for which

$$S_K^Q = \frac{QK}{\sqrt{6}} \simeq 2Q, \quad \text{for } Q > 1 \tag{38}$$

4. Conclusions

Two novel active RC bandpass networks are given using the second generation current conveyor as the active building block. Design equations are given, and the tuning procedure is discussed. Both realizations are canonic.

References

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