Equal-R, Equal-C Current Mode Butterworth Lowpass Filters

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SUMMARY New grounded capacitor realizations of second order and third order current mode Butterworth lowpass filters are given. The proposed circuits employ the current conveyor as the active element, and have the attractive property of using equal valued capacitors and equal valued resistors. PSpice simulation results are included.

key words: current mode filters

1. Introduction

Several active RC circuits are available for realizing the Butterworth lowpass characteristics, using the voltage controlled voltage source as the active element [1]–[4]. All these realizations can be transformed to realize current transfer functions using the adjoint network theorem [5]. The Butterworth current mode circuits obtained will have equal-valued capacitors but the resistor values will not be equal. Recently a current mode third order Butterworth lowpass filter with equal-valued components and using the current conveyor (CCII) has been proposed [6]. The circuit given in [6] employs five resistors, which is two resistors more than the minimum number needed to realize a third order lowpass characteristics.

In this letter new current mode realizations of the second order and the third order Butterworth lowpass filters using the CCII and employ equal-valued capacitors and equal-valued resistors are proposed.

Two types of the CCIIIs are employed in the filter circuits that are considered in this letter. The first is the single output CCII and the second is the two-output CCII. The single output CCII is a three port active building block which is described by the following matrix equation:

\[
\begin{bmatrix}
V_x \\
I_y \\
I_z
\end{bmatrix} =
\begin{bmatrix}
0 & 1 & 0 \\
0 & 0 & 0 \\
\pm 1 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
I_x \\
V_y \\
V_z
\end{bmatrix}
\]  

(1)

The positive sign results in a CCII+, on the other hand the negative sign results in a CCII−. The two-output CCII is a four port active building block which is defined by the following matrix equation:

\[
\begin{bmatrix}
V_x \\
I_y \\
I_{x1} \\
I_{x2}
\end{bmatrix} =
\begin{bmatrix}
0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 \\
\pm 1 & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
I_x \\
V_y \\
V_{x1} \\
V_{x2}
\end{bmatrix}
\]  

(2)

The positive sign results in a double output CCII, whereas the negative sign results in a balanced output CCII.

The two-output CCII has the advantage that current feedback can be adapted utilizing the additional output terminal of the CCII. Of course the practical CMOS circuit realization of a two-output CCII requires more transistors to deliver the second output current [7].

2. Second Order Lowpass Filters

In this section, two new circuits are given for realizing the second order Butterworth characteristics. The first circuit employs three single output CCIIIs, three resistors and two capacitors. The second proposed circuit which employs a single output CCII and a two-output CCII has the advantage of using only two resistors and two capacitors (minimal passive components).

2.1 The First Proposed Circuit

The first proposed equal C, equal R circuit which realizes a second order Butterworth characteristics is shown in Fig. 1(a). The current transfer function is given by:

\[
T_i(s) = \frac{R_2/R_3}{s^2C_1C_2R_1R_2 + s(C_1R_1 + C_2R_2) + 2}
\]  

(3)

Taking \(C_1 = C_2\), \(R_1 = R_2\), the circuit realizes a Butterworth lowpass response with a DC gain = \(R_2/2R_3\). It is seen that the DC gain is controlled by \(R_3\) which can be taken equal to the other two resistors resulting in a DC gain of 0.5. It should be noted that the third CCII and \(R_3\) realize a transconductance amplifier with \(g_m = 1/R_3\). The polarity of the third CCII is arbitrary and it can be taken as a CCII+ resulting in a negative DC gain. It is worth noting that the polarities of the first and second CCIIIs must be opposite to each other.

It is clear that the realization of Fig. 1(a) uses one resistor more than minimum number needed, namely two. This resistor however provides independent control on the DC gain.
2.2 The Second Proposed Circuit

The second proposed equal $C$, equal $R$ circuit which realizes a second order Butterworth characteristics is shown in Fig. 1(b). The current transfer function is given by:

$$T_i(s) = \frac{1}{s^2C_1C_2R_1R_2 + s(C_1R_1 + C_2R_2) + 2} \quad (4)$$

With $C_1 = C_2$ and $R_1 = R_2$, a Butterworth response is achieved. It should be noted that there is no control on the DC gain which equals 0.5.

3. Third Order Lowpass Filters

Two new realizations of the third order Butterworth

![Circuit Diagram](a)

Fig. 1 (a) Equal $C$, equal $R$, second order Butterworth filter. (b) Equal $C$, equal $R$, minimal component second order Butterworth filter.

![Circuit Diagram](a)

Fig. 2 (a) Equal $C$, equal $R$, minimal component third order Butterworth filters.

![Graph](a)

Fig. 3 PSpice simulation of the circuit of Fig. 2(b).
lowpass filter using three equal resistors, three equal capacitors and three CCIIs are shown in Fig. 2.

Figure 2(a) represents the first proposed third order lowpass filter, whose transfer function is given by:

$$Ti(s) = 1/\{s^3C_1C_2C_3R_1R_2R_3$$
$$+ s^2(C_1C_2R_1R_2 + C_2C_3R_2R_3)$$
$$+ s(C_2R_2 + C_3R_3) + 1\} \quad (5)$$

Taking $C_1 = C_2 = C_3 = C$ and $R_1 = R_2 = R_3 = R$, a third order Butterworth characteristics is obtained.

The second proposed circuit is shown in Fig. 2(b). The transfer function is given by:

$$Ti(s) = 1/\{s^3C_1C_2C_3R_1R_2R_3$$
$$+ s^2(C_1C_2R_1R_2 + C_1C_3R_1R_3)$$
$$+ s(C_1R_1 + C_3R_3) + 1\} \quad (6)$$

Again a third order Butterworth response is obtained using equal-valued resistor and equal-valued capacitor components.

PSpice simulation for the circuit of Fig. 2(b) is performed with $R = 10 \text{ K\Omega}$ and $C = 0.1 \text{nF}$ and using the CMOS CCI given in [7]. Figure 3 represents the simulated frequency response, from which it is seen that it is very close to the ideal response.

4. Conclusions

New current mode second order and third order Butterworth lowpass filters are given. The proposed circuits employ equal valued components, and have the advantage of using grounded capacitors. The circuits of Fig. 1(b) and Fig. 2 employ the minimum number of passive elements and have the advantage that the parasitic elements of the CCIIs, namely $R_x$ and $C_x$ can be absorbed in the circuit components.

References