MULTI-FUNCTION ACTIVE-ONLY HIGH-ORDER CURRENT-DRIVEN FILTER

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A new multi-function high-order current-driven filter is proposed. The filter uses only operational amplifiers, and operational transconductance amplifiers (OTAs). Without using any external passive elements, a variety of high-order input-current/output-current and/or input-current/output-voltage responses can be realised without changing the circuit topology and without any matching or cancellation conditions. The parameters of the high-order filter responses can be electronically tuned by adjusting the bias currents of the OTAs.

Keywords: Active filters; Operational amplifiers; Operational transconductance amplifiers

INTRODUCTION

At present, there is a growing interest in designing capacitorless-resistorless current-mode active-only filters using only active-elements, such as operational amplifiers (OAs) and operational transconductance amplifiers (OTAs). This is attributed to their integratability, programmability and wide frequency range of operation [1, 2]. The circuits reported in [1, 2] can realise second-order lowpass, highpass, bandpass and notch transfer functions, without any matching or cancellation conditions. Realisation of allpass transfer functions is also feasible.

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The work to be presented in this paper is an attempt to extend the applications of capacitorless-resistorless active-only realisations to the domain of high-order filters. Obviously, high-order filters can be obtained by cascading second-order realisations. However, this approach usually requires an extensive number of active components. For example, the realisation of an $N$th-order response, $N=\text{even}$ integer, using the structure proposed in [2] requires $N$ OAs and $5N/2$ OTAs. Similarly, the realisation of an $N$th-order response using the structure proposed in [1] requires $3N/2$ OTAs and $N$ OAs. It will be shown, in this paper, that an $N$th-order response, with $N=\text{even}$ integer, can be realised using $N$ OAs and $N+1$ OTAs only. Thus, the proposed realisation saves $(N/2-1)$ OTAs. Moreover, while the realisations of [1] and [2] can support only one output response at a time, the proposed realisation can simultaneously support a variety of output responses.

PROPOSED CIRCUIT

The proposed circuit is shown in Figure 1. Using standard notations, the OTA can be characterised by $i = g_{mk}(v_+ - v_-)$, where $g_{mk} = (I_{ABCk}/2V_T)$ is the transconductance of the $k$th OTA, $I_{ABCk}$ is the auxiliary bias-current, $V_T$ is the thermal voltage and $v_+$ and $v_-$ are...
the input voltages of the OTA. Assuming internally compensated operational amplifiers with open-loop gain of $A = (B_k/s)$, where $B_k$ is the gain-bandwidth product of the $k$th operational amplifier, routine analysis yields the current transfer functions given by

$$I_{o_k} = \frac{(g_{m_k}/g_{m_0}) \prod_{m=1}^{k} B_m s^{n-k}}{s^n + (g_{m_1}/g_{m_0})B_1 s^{n-1} + (g_{m_2}/g_{m_0})B_1 B_2 s^{n-2} + \cdots + (g_{m_n}/g_{m_0}) \prod_{m=1}^{n} B_m a_k s^{n-k}}$$

and the voltage transfer functions given by

$$V_{o_k} = \frac{1/g_{m_0}}{s^n + (g_{m_1}/g_{m_0})B_1 s^{n-1} + (g_{m_2}/g_{m_0})B_1 B_2 s^{n-2} + \cdots + (g_{m_n}/g_{m_0}) \prod_{m=1}^{n} B_m c_k s^{n-k}}$$

Thus, the circuit of Figure 1 can, simultaneously, support $(n+1)$ high-impedance output currents and $n$ low-impedance output voltages.

From (1) and (2) the parameters $a_k$, $k = 0-n$ and $c_k$, $k = 1-n$ can be expressed as

$$a_k = \frac{g_{m_k}}{g_{m_0}} \prod_{m=1}^{k} B_m$$

and

$$c_k = \frac{a_k}{g_{m_k}}$$

And the parameters $b_l$, $l = 1-n$ can be expressed as

$$b_l = \frac{g_{m_l}}{g_{m_0}} \prod_{m=1}^{l} B_m$$

From (5) it can be seen that the parameters $b_l$, $l = 1-n$ can be independently adjusted by controlling the transconductances $g_{m_l}$, $l = 1-n$. Thus, the proposed circuit enjoys electronic tunability of its parameters.
SIMULATION RESULTS

The circuit of Figure 1 was used to realise the 4th-order lowpass Butterworth current transfer function given by (Tab. 2.2 of [3])

\[
H(s) = \frac{1}{s^4 + 2.61312593s^3 + 3.41421356s^2 + 2.61312593s + 1} \quad (6)
\]

Equation (6) can be written in a normalised form as follows

\[
H\left(\frac{s}{\omega_o}\right) = \frac{\omega_o^4}{s^4 + 2.61312593\omega_o s^3 + 3.41421356\omega_o^2 s^2 + 2.61312593\omega_o^3 s + \omega_o^4} \quad (7)
\]

With \(\omega_o = 2\pi \text{Mrad/sec}, \ B = 2\pi(4.1345) \text{Mrad/sec}\) and if we choose \(g_{m_0} = 200 \mu\text{A/V}\) then \(g_{m_1} = 126.41 \mu\text{A/V}, \ g_{m_2} = 39.95 \mu\text{A/V}, \ g_{m_3} = 7.395 \mu\text{A/V}, \ g_{m_4} = 0.684 \mu\text{A/V}\). The operational amplifier LF156, with \(B = 2\pi(4.1345) \text{Mrad/sec}\) and the OTA macromodel [4] were used in simulation. With a dc supply \(\pm 10 \text{V}\), the results obtained are shown in Figure 2. It appears from Figure 2 that the agreement between simulated and theoretical results is good.

![Figure 2](image-url)
CONCLUSION

A new $N$th-order current-driven filter has been presented. The proposed filter uses only operational amplifiers and operational transconductance amplifiers. No external passive elements are used. The proposed circuit enjoys the following advantages:

(a) Independent current control of the filter parameters.
(b) Simultaneous support of $n+1$ different high-impedance output-current responses and $n$ different low-impedance output-voltage responses.
(c) Insensitivity to the temperature variations of the transconductances of the OTAs. Moreover, using operational amplifiers with temperature compensated gain-bandwidth products [5], high-order responses with temperature-insensitive parameters can be realised.

References
