Three-input one-output voltage-mode universal filter using FTFN and OTA

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Received 23 July 2003, revised 17 December 2003, accepted 26 December 2003

A three-input one-output voltage-mode universal biquad capable of realizing lowpass (LP), highpass (HP), bandpass (BP), allpass (AP) and Notch filtering signals from the same configuration without any component matching conditions or cancellation constraints is presented. The proposed topology is based on and employing a single four terminal floating nullor (FTFN), a single operational transconductance amplifier (OTA), and three passive components. The circuit facilitates the tuning of cut-off frequency $\omega_0$ and bandwidth $\omega_0/Q$ in an orthogonal manner. The circuit has low sensitivity figures and is canonical as it employs a minimum number of passive components. To verify the theoretical calculations experimental and simulated results are included.

[Keywords: Four terminal floating nullor, Operational transconductance amplifier, Voltage-mode universal filter, Continuous-time circuits, Electronic tunability]

IPC Code : H03H 15/00

1 Introduction

The available literature of recent works pertaining to the development of continuous-time circuits shows that FTFN is a more flexible and versatile building block than an operational amplifier (OA) or a second generation current conveyor (CCII), leading to the shift in the trend of research activities towards simulating FTFN based circuits 1-4. This promises the development of continuous-time circuits negotiating most of the salient features offered by IC design techniques. But one inherent drawback of this block is that it is devoid of programmability feature, which is so essential from the viewpoint of IC design consideration, however the same can be circumvented using the combination of FTFN and OTA. Some universal voltage-mode filter circuits using current feedback amplifiers (CFA) or CCIIIs 5-9 with three inputs and one output and the universal filter based on two FTFNs and five passive components 10 have been reported in the literature. It appears that there has been less endeavour towards the development of FTFN based voltage-mode filters. The circuit based on a single FTFN and a single OTA having three inputs and one output has not been reported in the available literature as yet. Further the combination of FTFN and OTA helps in the accomplishment of electronic tunability feature of the filtering characteristics.

Towards this end a new voltage-mode universal filter with three inputs and one output is proposed. The circuit has been constructed using one each of FTFN and OTA together with three passive components and realizes from the same topology all the generic filtering signals LP, HP, BP, AP, and Notch through the suitable choice of inputs. The circuit employs a minimum number of passive components. One of the filtering characteristics either bandwidth $\omega_0/Q$ or cut-off frequency $\omega_0$ can be electronically tuned through transconductance gain $g_m$ of OTA while the other can be controlled by passive components. The sensitivity figures of parameters of interest have been found to be less than unity, ensuring improved performance of the filter.

2 Circuit Analysis

The negative FTFN can be characterized by the port relations with $V_X = V_Y$, $I_X = I_Y = 0$ and $I_W = -I_Z$. For OTA we have $I_0 = g_m(V^+ - V^-)$ where $g_m$ is the transconductance gain of OTA. The analysis of the circuit in Fig.1 yields the following equations:

\[
\frac{(V_1 - V_0)}{R_1} = -(V_2 - V_4)sC_3 \quad \ldots (1)
\]

\[
(V_4 - V_0)g_m = (V_0 - V_2)sC_2 \quad \ldots (2)
\]

By eliminating $V_4$ in the Eqs (1) and (2), the transfer function in voltage-mode is obtained and is given by

\[
V_0 = \frac{V_2s^2C_2C_3 + V_3sC_3g_m + V_1g_m}{R_1} \ldots (3)
\]

\[
V_0 = \frac{s^2C_2C_3 + sC_3g_m + \frac{g_m}{R_1}}{R_1}
\]
It is clear from Eq. (3) that the circuit is capable of realizing LP, HP, BP, AP, and Notch filtering signals through the suitable choice of inputs. The circuit implements the filtering functions without any change to be required in the circuit architecture and/or the nature of components however the realization of AP filtering response needs an inverter. The various filtering responses can be obtained from Eq. (3) as under:

I. a second-order HP is obtained with \( V_2/V_1 \) by choosing \( V_1 = V_2 = 0 \).

II. a second-order BP is obtained with \( V_2/V_3 \) by choosing \( V_3 = 0 \).

III. a second-order LP is obtained with \( V_2/V_1 \) by choosing \( V_1 = V_2 = 0 \).

IV. a second-order Notch is obtained with \( V_2/V_m \) by choosing \( V_1 = V_2 = V_3 = V_{in} \).

V. a second-order AP is obtained with \( V_2/V_m \) by choosing \( V_1 = V_2 = -V_3 = V_{in} \).

The parameters \( \omega_o, \omega_o/Q \), and \( Q \) are given by

\[
\omega_o = \sqrt{\frac{g_m}{C_2C_3R_1}} \quad \text{...(4)}
\]

\[
\frac{\omega_o}{Q} = \frac{g_m}{C_2} \quad \text{...(5)}
\]

\[
Q = \frac{C_2}{g_mC_3R_1} \quad \text{...(6)}
\]

An examination of Eqs (4) and (5) shows that orthogonal tuning of \( \omega_o/Q \) and \( \omega_o \) can be achieved by adjusting former parameter of interest through the transconductance gain \( g_m \) of OTA and/or \( C_2 \) and the latter through \( R_1 \) and/or \( C_3 \) in that order. The sensitivity figures are inferior to unity and are given by

\[
S_{g_m}^{\omega_o} = -S_{C_2,C_3,R_1}^{\omega_o} = \frac{1}{2}
\]

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S_{C_2}^{\omega_o} = -S_{g_mC_3,R_1}^{\omega_o} = \frac{1}{2}
\]

3 Experimental Results

Experimental and simulation tests were performed to verify the functionality of the circuit. For experimental test the negative FfFN was constructed with commercial current feedback op-amp IC AD844 and OTA which is commercially available as an integrated circuit CA3080 of Analog Devices. PSPICE simulations were performed using AD844 macromodal of Analog Devices to construct FfFN.CA3080 macromodal of OTA with \( R_f = 100k\Omega, C_3 = 2.6pF, R_o = 70 MQ \) and \( C_2 = 3.6 pF \) was used and its implementation is shown in Fig. 2. The negative FfFN can be implemented by using two AD844s supported by Analog Devices and is shown in Fig. 3. To realize HP, BP, LP and Notch filtering functions the passive components were chosen with \( R_f = 10k\Omega, C_2 = 10 nF, C_3 = 4 nF \) and \( g_m = 0.1 \text{ mmho} \). This option gives the resonant frequency \( f_o = 2.51 \text{ kHz} \) and quality factor \( = 1.58 \).

4 Conclusion

A new FfFN, a sin, been presented with the following features:

1. Implement the same matching
2. Has low \( \omega_o/Q \)
3. Is canonical

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formed to the experimental test current which is used using the constructs and its FTFN can be emulated by HP, BP, components 4 nF and frequency experimental and simulated results obtained are in good agreement with the theory.

4 Conclusion

A new voltage-mode universal filter using a single FTFN, a single OTA and three passive components has been presented. The filter circuit enjoys the following salient features:

1. Implementing all the generic filtering functions from the same configuration without any component matching conditions or cancellation constrains.
2. Has low sensitivity figures and orthogonal control of $\omega_n/Q$ and $\omega_p$.
3. Is canonical as it employs minimum number of passive components.

References