High input impedance voltage-mode lowpass, bandpass, highpass and notch filter using current feedback amplifiers

N A Shah & M A Malik
Postgraduate Department of Electronics & Instrumentation Technology, The University of Kashmir, Srinagar, 190 006, India

Received 9 December 2004; accepted 9 May 2005

The paper presents a new voltage-mode (VM) high input impedance filter having a single input and four low impedance outputs. The proposed circuit employs four current feedback amplifiers (CFAs) and six passive elements, four of them are grounded and enjoys the following advantages: simultaneous realisation of lowpass (LP), bandpass (BP), highpass (HP) and notch filtering functions explicitly, cascadability, independent control of resonance frequency ($\omega_0$) and bandwidth ($\omega_0/Q$), orthogonal control of resonance frequency ($\omega_0$) and quality factor ($Q$), no requirements for component matching conditions, use of two grounded capacitors which are ideal for IC implementation and low passive sensitivity figures. Experimental and PSPICE simulation results are given to verify the theoretical calculations.

IPC Code: H03F3/00, H03H3/00

From a current-mode filter, one would expect low input impedance and high output impedance while as from a voltage-mode filter, one would anticipate high input impedance and low output impedance. The high input and low output impedance voltage-mode (VM) filters are of great interest because several such filters can be directly connected in cascade to implement higher order filtering signals without interposing any active separating stages. Further, the infinite input impedance cells ensure a total uncoupling between the different elementary stages which entails an easier determination of the passive component values of each of the elementary cells. The applications and advantages in realising active filter transfer functions using current feedback amplifiers have received great attention because the amplifier enjoys the features of constant bandwidth independent of closed-loop gain and high slew rate, besides having low output impedance. Thus, it is advantageous to use CFA as a basic building block in the accomplishment of various analog signal processing tasks. A number of filter circuits built around CFA are reported in the literature. One of the high input and low output impedance filters based on two CFAs and five passive components has limited scope of application as it realises either a bandpass or a lowpass or a highpass response. The three filter functions can’t be simultaneously realised without changing the topology of the circuit. Further, the two topologies of the circuit use floating capacitors.

In this paper, we present a new high input impedance voltage-mode filter configuration having a single input and four low impedance outputs, employing four CFAs and six passive components four of them are grounded. The proposed circuit enjoys the following features vis-à-vis the reported one: simultaneously realizes four responses LP, BP, HP and notch, offers saving of one passive component and employs only two grounded capacitors. However, the proposed circuit employs only one extra CFA than the reported one to implement the notch filtering function. The filter permits cascadability to obtain higher order filters. The filtering functions are realized without any component matching conditions or cancellation constraints. The circuit uses two grounded capacitors which are ideal for integration. The resonance frequency ($\omega_0$) and bandwidth ($\omega_0/Q$) are independently controllable. Moreover, the resonance frequency ($\omega_0$) and quality factor ($Q$) can be orthogonally tuned. The passive sensitivities are small.

**Circuit Description**

CFA is a four terminal device characterized by the port relations with $V_x = V_y, V_0 = V_z, I_y = 0$, and $I_x = I_z$. The analysis of the circuit in Fig.1 yields the following two equations

\[
(V_{NH} - V_{in})G_1 = -V_{LP}sC_3 = V_{BP}G_2 
\]

\[
V_{BP}sC_4 = (V_{LP} - V_{NH})G_5 = -V_{HP}G_6
\]
Solving the above two equations yields the voltage-mode transfer functions for lowpass, bandpass, highpass and notch responses respectively as given by

\[
\frac{V_{LP}}{V_{in}} = \frac{G_1 G_5}{s^2 C_3 C_4 G_1 + s C_3 G_2 G_5 + G_1 G_2 G_5} \quad \ldots \ (3)
\]

\[
\frac{V_{BP}}{V_{in}} = \frac{\left(\frac{G_1}{G_2}\right) s C_3 C_4 G_1}{s^2 C_3 C_4 G_1 + s C_3 G_2 G_5 + G_1 G_2 G_5} \quad \ldots \ (4)
\]

\[
\frac{V_{HP}}{V_{in}} = \frac{\left(\frac{G_5}{G_6}\right) s^2 C_3 C_4 G_1}{s^2 C_3 C_4 G_1 + s C_3 G_2 G_5 + G_1 G_2 G_5} \quad \ldots \ (5)
\]

\[
\frac{V_{NL}}{V_{in}} = \frac{G_1 (s^2 C_3 C_4 + G_2 G_5)}{s^2 C_3 C_4 G_1 + s C_3 G_2 G_5 + G_1 G_2 G_5} \quad \ldots \ (6)
\]

In realizing these filtering responses it can be seen from the above equations that no component matching or cancellation constraints are imposed. The filtering parameters \(\omega_n\), \(\omega_n / Q\) and \(Q\) are given by

\[
\omega_n = \sqrt{\frac{G_1 G_5}{C_3 C_4}} \quad \ldots \ (7)
\]

\[
\omega_n / Q = \frac{G_5}{G_1 C_4} \quad \ldots \ (8)
\]

\[
Q = G_1 \sqrt{\frac{C_4}{G_4 G_5 C_3}} \quad \ldots \ (9)
\]

An examination of Eqs (7) and (8) shows that independent tuning of \(\omega_n\) and \(\omega_n / Q\) can be achieved by adjusting \(C_3\) and \(R_1\) in that order. Also one can see from Eqs (7) and (9) that \(\omega_n\) and \(Q\) can be orthogonally tuned. From Eqs (4) and (5) the passband gains for BP and HP responses are respectively given by

\[
G_{BP} = \frac{G_1}{G_2} = \frac{R_2}{R_1} \quad \ldots \ (10)
\]

\[
G_{HP} = \frac{G_5}{G_6} = \frac{R_6}{R_5} \quad \ldots \ (11)
\]

The passband gains for BP and HP can be independently adjusted by the corresponding resistors. Adjustment of gain for BP by the grounded resistor \(R_2\) can change \(\omega_n\) as well as \(Q\) however adjustment...
by the resistor \( R_1 \) has no influence on \( \omega_c \). In case of passband gain for HP, the adjustment can be achieved through the grounded resistor \( R_6 \) which has no influence on \( \omega_c \) and \( Q \).

The sensitivity figures are small and are given by

\[
S_{G2,G5}^{\omega_0} = -S_{C3, C4}^{\omega_0} = \frac{1}{2}
\]

\[
S_{C4}^{Q} = -S_{C3,G2,G5}^{Q} = \frac{1}{2}
\]

\[
S_{G1}^{Q} = 1.
\]

**Experimental and Simulation Results**

The proposed filter was experimentally tested and simulated by the PSPICE circuit simulation program. Plus-type CFA can be implemented by using commercially available AD844 and macro-modal of AD844 supported by analog devices. The circuit was built with passive component values \( R_1 = R_2 = R_5 = R_6 = 5 \, \text{k}\Omega \) and \( C_3 = C_4 = 4 \, \text{nF} \). This option gives the resonant frequency \( f_0 = 7.96 \, \text{kHz} \) and quality factor \( Q = 1 \). Fig. 2 shows results for LP, BP, HP and notch filtering functions. As an illustration of the adjustment of bandpass gain, Fig. 3 shows results of BP gains obtained for \( R_1 = 5, 2, 0.5 \, \text{k}\Omega \) which yields \( Q = 1, 2.5, 10 \) respectively at the same resonant frequency. The results obtained agree with the theory.

**Conclusions**

A new high input impedance filter with a single input and four low impedance outputs has been described. The circuit employs four CFAs and six passive components and simultaneously realises LP, BP, HP and Notch filtering functions without any component matching or cancellation constraints. The filter is cascaddable and employs two grounded capacitors which are ideal for integrated circuit implementation. The resonance frequency and bandwidth are independently tunable. Further, the resonance frequency and quality factor can be orthogonally tuned. The passive sensitivity figures are low.

**References**