Frequenz
53 (1999)
7-8

Insensitive Multifunction Filter Implemented with Current Conveyors and only Grounded Passive Elements

Multifunktionsfilter mit kleinen Schwankungsempfindlichkeiten auf Basis von Stromübertragern unter ausschließlicher Nutzung passiver einseitig geerdeter Bauelemente

Abstract
The paper presents a new multifunction filter which can simultaneously realise low-pass, high-pass and band-pas functions. The circuit employs only positive-type second generation current conveyors, grounded passive components and exhibits high input impedance. No element matching conditions are imposed. The filter permits orthogonal adjustment of quality factor Q and ω_0. For one possible set of component selection the filter permits compensation for the parasitics. The passive sensitivities are shown to be low.

Übersicht
In der vorliegenden Arbeit wird ein neues Multifunktionsfilter für simultane Tiefpaß-, Hochpaß- und Bandpaßfunktion vorgestellt. Der Schaltkreis beinhaltet ausschließlich Stromübertrager der zweiten Generation mit positiver Übertragungsfaktor sowie einseitig geerdete passive Bauelemente und zeichnet sich durch eine hohe Eingangsimpedanz aus. Nebenbedingungen für die Elemente sind nicht gefordert. Die Güte Q und die Resonanzkreisfrequen ω_0 können unabhängig voneinander eingestellt werden. Für einen möglichen Satz ausgewählter Komponenter können die parasitären Elemente kompensiert werden. Die Empfindlichkeiten gegenüber Änderungen der passiver Elemente sind gering.

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Für die Dokumentation
Stromübertrager / Multifunktionsfilter

1. Introduction

Several multifunction filters are presented recently employing second generation current conveyors [1-4], which are accepted to have wider bandwidth and greater linearity compared to voltage mode op-amps. The presented topologies in the literature employ at least four second generation current conveyors to realise low-pass, high-pass and band-pass functions simultaneously. Some topologies employ both grounded and floating passive components [3], but some of them employ only grounded elements [4]. In [3] five different circuits are presented with only two grounded capacitors but employing also floating resistors, the number of resistors is as low as three for a topology. But the filters do not show high input impedance.

This paper presents a new topology with four current conveyors only positive type which is commercially available and with only grounded passive components which is advantageous from the integrated circuit implementation point of view [5-6]. No component matching condition is imposed. The filter permits orthogonal adjustment of quality factor Q and resonant angular frequency ω_0. The presented circuit realises low-pass, high-pass and band-pass filter functions simultaneously. The circuit uses the y-terminal as filter input which implies high input impedance, therefore it permits easy cascade connection. The number of active components is less than in Soliman [1] (three positive-type two negative-type), Senani and Singh [2] (two positive-type three negative-type) circuits, furthermore all of positive type as the circuit given in [4]. The number of passive components can be selected as low as three capacitors and five resistors which is not more than the circuit shown in [4]. The proposed filter however has the following distinct advantage: From the many selection possibilities which are given in tabular form, for one possible set of selected passive elements, the filter can be made insensitive to parasitic capacitances at the z- and y-terminals. Furthermore for the non-ideal output resistance at the x-terminal easy compensation is possible by the grounded only-resistors connected to these terminals. Therefore the filter permits precise realisation of filter functions, quality factor Q and resonant angular frequency ω_0. Experimental results confirm well the the ry.

2. The Proposed Circuit

The new multifunction filter is shown in Fig. 1. The relations between voltages and currents of the CCII are given ideally by $i_y(t)$ 0, $v_x(t) = v_y(t)$ and $i_z(t) = \pm i_x(t)$ but by $i_y(t) = 0$, $v_x(t) = (1+\varepsilon_v)v_y(t)$ an $i_z(t) = \pm(1+\varepsilon_i)i_x(t)$ if the current conveyor nonidealities are take into account. In the equations $|\varepsilon_i| \ll 1$ and $|\varepsilon_v| \ll 1$ represent th current and voltage tracking errors of the current conveyor. Th analysis of the circuit in Fig. 1 for the transfer functions yields

$$\frac{v_{01}}{v_i} = \frac{y_1 y_2 y_3}{y_4\left(y_5 y_6 + y_2 y_7\right)}, \tag{1a}$$

$$\frac{v_{02}}{v_i} = \frac{y_3 y_6}{y_5 y_6 + y_2 y_7}, \tag{1b}$$

$$\frac{v_{03}}{v_i} = \frac{y_2 y_3}{y_5 y_6 + y_2 y_7}. \tag{1c}$$

Many different possible set of selections for y_1 to y_7 is possibl that enable simultaneous realisation of LPF, BPF and HPF. On possible selection with only three capacitors and five resistors is a follows: $y_1 = sC_1$, $y_2 = sC_2$, $y_3 = G_3$, $y_4 = G_4$, $y_5 = G_5$, $y_6 = G$ $y_7 = sC_7 + G_7$, which realises the following transfer functions:

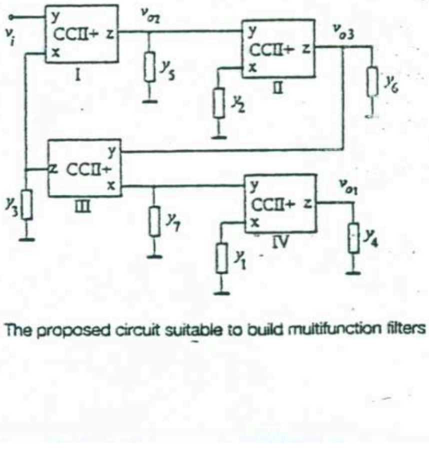

Fig. 1: The proposed circuit suitable to build multifunction filters

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$$\frac{v_{01}}{v_i}=\frac{s^2C_1C_2G_3}{G_4\left(G_5G_6+sC_2G_7+s^2C_2C_7\right)}, \tag{2a}$$

$$\frac{v_{02}}{v_i}=\frac{G_3G_6}{G_5G_6+sC_2G_7+s^2C_2C_7}, \tag{2b}$$

$$\frac{v_{03}}{v_i}=\frac{sC_2G_3}{G_5G_6+sC_2G_7+s^2C_2C_7}, \tag{2c}$$

and

$$\omega_0=\sqrt{\frac{G_5G_6}{C_2C_7}}$$

$$Q=\frac{1}{G_7}\sqrt{\frac{G_5G_6C_7}{C_2}}. \tag{3}$$

Note that independent control of ω_0 and Q is possible. Furthermore the ω_0 and Q sensitivities are given by

$$S^{\omega_0}_{G_5,G_6}=-S^{\omega_0}_{C_2,C_7}=\frac{1}{2},\ S^{Q}_{G_5,G_6,C_7}=-S^{Q}_{C_2}=\frac{1}{2},\ S^{Q}_{G_7}=-1.$$

Thus ω_0 and Q sensitivities are no more than unity. Moreover the gain can be adjusted independently without disturbing ω_0 and Q by G_3. The above selection is shown in **Table 1** as realisation 4. Other possible selections for passive elements are also given in Table 1.

Non-ideal case: Two different non-idealities should be discussed. The first nonideality is due to current- and voltage-tracking errors which are usually small. The second non-ideality is due to non-zero output resistance at the x-terminal and the finite output resistance at the z-terminal which results a loading effect. For practical resistance values on the order of kilo ohms r_x may cause significant errors. For AD844, r_x is about 60 Ω, thus any grounded impedance connected to the x-terminal if comparable to 60 Ω will load heavily the terminal and disturb the filter function. For CMOS versions of CCII, r_x is even higher up to several hundreds of ohms. Therefore special care is needed when selecting appropriate component values in general. However, if the reduced number of capacitors condition is relaxed a selection with the same number of passive elements but with an interesting property arises. Consider the selection (Table 1, realisation 1) $y_1 = G_1$, $y_2 = G_2$, $y_3 = sC_3$, $y_4 = sC_4$, $y_5 = sC_5 + G_5$, $y_6 = sC_6$, $y_7 = G_7$, which realises the following transfer functions:

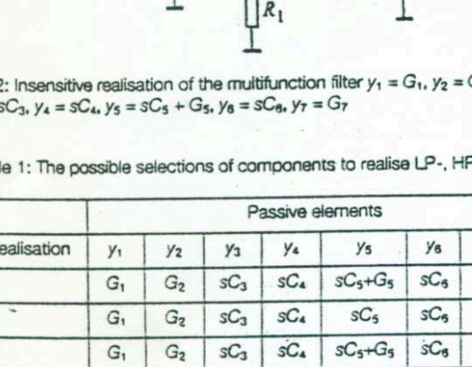

Fig. 2: Insensitive realisation of the multifunction filter $y_1 = G_1$, $y_2 = G_2$, $y_3 = sC_3$, $y_4 = sC_4$, $y_5 = sC_5 + G_5$, $y_6 = sC_6$, $y_7 = G_7$

$$\frac{v_{01}}{v_i}=\frac{C_3G_1G_2}{C_4\left(G_2G_7+sC_6G_5+s^2C_5C_6\right)}, \tag{4a}$$

$$\frac{v_{02}}{v_i}=\frac{s^2C_3C_6}{G_2G_7+sC_6G_5+s^2C_5C_6}, \tag{4b}$$

$$\frac{v_{03}}{v_i}=\frac{sC_3G_2}{G_2G_7+sC_6G_5+s^2C_5C_6}, \tag{4c}$$

and

$$\omega_0=\sqrt{\frac{G_2G_7}{C_5C_6}}$$

$$Q=\frac{1}{G_5}\sqrt{\frac{G_2G_7C_5}{C_6}}; \tag{5}$$

therefore the filter again permits independent control of ω_0 and Q. Furthermore the ω_0 and Q sensitivities are given by

$$S^{\omega_0}_{G_2,G_7}=-S^{\omega_0}_{C_5,C_6}=\frac{1}{2},\ S^{Q}_{G_2,G_7,C_5}=-S^{Q}_{C_6}=\frac{1}{2},\ S^{Q}_{G_5}=-1.$$

Thus ω_0 and Q sensitivities are no more than unity as it is in the previous case. Moreover, the gain can be adjusted independently without disturbing ω_0 and Q by C_3.

The above selection of passive elements permits an insensitive realisation to parasitic capacitances and enables easy compensation for the r_x of the current conveyor as shown in Fig. 2. In Fig. 2 one can easily see that grounded capacitors are connected to the z-terminals of all current conveyors for easy compensation of the stray capacitance which is on the order of 4.5 pF for AD844 and becomes important at higher frequencies. Furthermore R_1 and R_2 can be selected by the amount of r_x less to compensate for r_x since no capacitors are connected to corresponding terminals. Thus for r_x of second and fourth current conveyor easy compensation is possible by the resistive y_1 and y_2. Moreover, the relation between v_{01} and v_{03} is ideally as follows

$$v_{01}=v_{03}\frac{1}{sC_4R_1}, \tag{6}$$

and if r_x is of the third and fourth current conveyor is considered

$$v_{01}=v_{03}\frac{R_7}{r_x+R_7}\frac{1}{sC_4\left(R_1+r_x\right)}. \tag{7}$$

Table 1: The possible selections of components to realise LP-, HP- and BP-functions simultaneously

	Passive elements							Denominator	Filter functions		
Realisation	y_1	y_2	y_3	y_4	y_5	y_6	y_7	Δ	v_{01}	v_{02}	v_{03}
1	G_1	G_2	sC_3	sC_4	sC_5+G_5	sC_6	G_7	$G_2G_7+sC_6G_5+s^2C_5C_6$	$(C_3G_1G_2/C_4)/\Delta$	$s^2C_3C_6/\Delta$	sC_3G_2/Δ
2	G_1	G_2	sC_3	sC_4	sC_5	sC_6	sC_7+G_7	$G_2G_7+sC_7G_2+s^2C_5C_6$	$(C_3G_1G_2/C_4)/\Delta$	$s^2C_3C_6/\Delta$	sC_3G_2/Δ
3	G_1	G_2	sC_3	sC_4	sC_5+G_5	sC_6	sC_7+G_7	$G_2G_7+s(C_7G_2+C_6G_5)+s^2C_5C_6$	$(C_3G_1G_2/C_4)/\Delta$	$s^2C_3C_6/\Delta$	sC_3G_2/Δ
4	sC_1	sC_2	G_3	G_4	G_5	G_6	sC_7+G_7	$G_5G_6+sC_2G_7+s^2C_2C_7$	$s^2(C_1C_2G_3/G_4)/\Delta$	G_3G_6/Δ	sC_2G_3/Δ
5	sC_1	sC_2	G_3	G_4	sC_5+G_5	G_6	sC_7	$G_5G_6+sC_5G_6+s^2C_2C_7$	$s^2(C_1C_2G_3/G_4)/\Delta$	G_3G_6/Δ	sC_2G_3/Δ
6	sC_1	sC_2	G_3	G_4	sC_5+G_5	G_6	sC_7+G_7	$G_5G_6+s(C_5G_6+C_2G_7)+s^2C_2C_7$	$s^2(C_1C_2G_3/G_4)\Delta$	G_3G_6/Δ	sC_2G_3/Δ

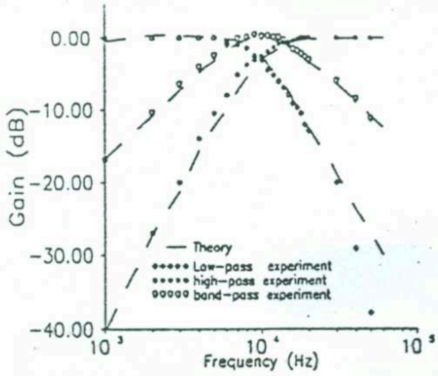

Fig. 3: The magnitude of the output v_0 vs frequency of the multifunction filter $C_3 = C_4 = C_5 = C_6 = 10$ nF, $R_1 = 2.2$ kΩ, $R_2 = 1.06$ kΩ, $R_5 = 1.125$ kΩ, $R_7 = 2.3$ kΩ, $f_0 = 10$ kHz, $Q = 0.707$

therefore r_x affects the gain for v_{01} only without disturbing ω_0 or Q and compensation for it is possible by R_1. The only r_x remaining uncompensated is the r_x of the first current conveyor. To minimise its effect is to make the x-terminal of it current controlled (high driving impedance) thus to choose the value of C_3 such that its impedance is much larger compared to r_x at the operating frequency.

The proposed filter exhibits the following additional advantages. All passive elements are grounded that enables easy digital control of ω_0 and Q if weighted elements are used. Also, if a JFET is used as voltage variable resistor these two parameters can easily be made voltage controlled. Moreover a band reject function can be obtained in expense of an additional current conveyor as summing element to add low-pass and high-pass outputs.

3. Experimental Verification and Discussion

The performance of the circuit is demonstrated on a Butterworth filter design example. The supply voltages are chosen as ±12 V. The following element values are selected: $R_1 = 2.2$ kΩ, $R_2 = 1.06$ kΩ, $R_5 = 1.125$ kΩ, $R_7 = 2.3$ kΩ, $C_3 = 10$ nF, $C_4 = 10$ nF, $C_5 = 10$ nF, $C_6 = 10$ nF. Using these values in Eq. (5) the resonant frequency is calculated as $f_0 = 10$ kHz and the quality factor is calculated as $Q_0 = 0.707$. The amplitude of input voltage v_i is taken as 2 V and held constant during the experiments. The magnitude of the output versus frequency is shown in Fig. 3; it is observed that the theoretical and experimental results are in good agreement as expected. To test the input dynamic range of the filter, the measurements are repeated for a larger amplitude input signal $v_i = 5$ V, satisfactory performance is observed up to 30 kHz signal frequency. Fig. 4 shows that the input dynamic range of the low-pass filter extends up to 8 V_{PP} without significant distortion. To illustrate the time domain response, a square wave input is applied to the filter and the output waveform is shown in Fig. 5.

4. Conclusions

In this paper a new current conveyor based multifunction filter is presented which can simultaneously realise low-pass, high-pass and band-pass functions. The filter employs only grounded passive components which is advantageous for integration and only positive-type second generation current conveyors which is commercially available. No element matching conditions are used, the filter permits orthogonal adjustment of quality factor Q and ω_0, and exhibits high input impedance. The passive ω_0 and Q sensitivities are shown to be low. For one possible set of component selection with eight passive elements the filter permits compensation for the parasitic capacitances and easy compensation for the loading error resulting from the non-zero output resistance at the x-terminal of the current conveyor. Another possible set employs only three capacitors and five resistors. Other possible selections are given in tabular form. Experimental results are included to verify theory.

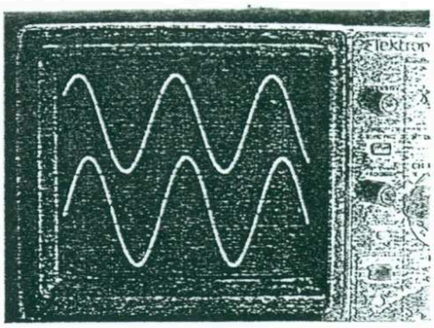

Fig 4: Time domain response of the low-pas filter (upper signal: input 2V/div, 50 µs/div scale; lower signal: output-uncalibrated vertical scale for better observation)

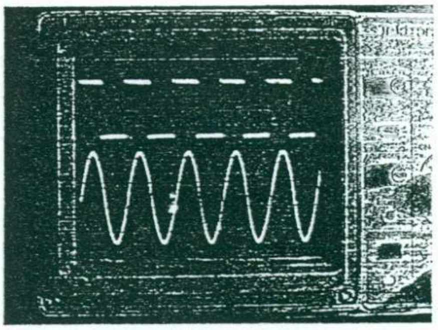

Fig 5: Time domain response of the low-pas filter to a square wave input (upper signal: input 2V/div, 50 µs/div scale; lower signal: output-uncalibrated vertical scale for better observation)

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(Received on August 19, 1998)