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A novel current controlled current mode universal filter: SITO approach

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Abstract: A novel electronically tunable single-input three-output (SITO) universal filter employing three current controlled conveyors and two grounded capacitors is presented. The proposed filter offers the following advantageous features: low input impedance and high output impedance- a desirable property of current mode filters, realization of low pass, band pass, high pass, notch and all pass signals from the same configuration, no matching constraint, low sensitivity performance and use of grounded capacitors ideal for integration. The validity of the proposed filter is verified through PSPICE simulations.

Keywords: current mode filters, current conveyors

Classification: Integrated circuits

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1 Introduction

Second generation current conveyors (CCIIs) are receiving growing attention as alternative building block for implementing continuous time filters operating in current mode (CM). They offer several advantages, such as wider signal bandwidths, greater linearity, larger dynamic range and lower power consumption, over the traditional voltage mode counterparts. CM circuits may also operate at lower power supply due to their small voltage swing. Moreover, they perform summing of current signals at a circuit node, which results in a simpler structure. From a voltage mode filter one would expect high input impedance and low output impedance. Similarly a current mode filter is expected to have a low input impedance and high output impedance to enable easy cascadability and to enable additional filter responses by simply connecting the outputs. Of particular concern here are universal filters (single-input three- output) as they permit realization of different filter functions from the same topology and thus bring cost reduction to the in-

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tegrated circuit manufacturer. Several implementations of CM single-input three-outputs (SITO) filters based on current conveyors [1, 2, 3, 4, 5, 6, 7, 8, 9] have been reported in the literature. The structures [1, 2, 3, 4, 5] use excessive number of active and passive elements. The structure [6] uses excessive number of active elements and minimum number of passive components but some of them are ungrounded which is not suitable for IC implementation [10]. The structures [7, 8] use three active elements but excessive passive elements and some of the passive elements are ungrounded in former one and a matching condition has to be satisfied for all pass response in the later one. Fabre and Alami [9] used minimum number of passive components but one of them is ungrounded and all the output currents (LP, HP, BP) are available on external passive components. Hence three more current conveyors will be required to implement other standard functions (Notch, AP) of universal filter. Moreover, many applications require filter tuning, in particular sophisticated techniques of signal processing demand the ability of the circuit to adapt filter characteristics dynamically. In such cases, it is desirable to vary the filter coefficients electronically. None of the above reported networks possesses electronic tunability and thus is not adaptable in such cases.

With recently introduced second generation current controlled conveyor (CCCII) [11], current conveyor's applications can be extended to the domain of electronically adjustable functions. Electronic adjustability is attributed to intrinsic resistance (R_x) at port x which depends on bias current (I_o). Therefore, in recent past, there has been greater emphasis on the design of current mode circuits using CCCIIs [12, 13, 14, 15, 16]. The structures [12, 13, 14] use 3 CCCIIs and two grounded capacitors whereas [15] uses 2 CCCIIs and two capacitors but one of the capacitors is floating. Either one or two of the outputs [12, 13, 14, 15] are available on passive components. Hence one or two additional current conveyor(s) will be required to implement all the standard universal filter functions (LP, HP, BP, Notch, and AP). The structure [16] enjoys high output impedance, but uses five active components and three grounded capacitors and needs to satisfy a matching condition of passive components to implement notch and AP functions. Moreover all these structures [12, 13, 15, 16] except [14] use capacitor at port x and hence limit the usage in high frequency range as a consequence [8].

In this paper a new SITO universal filter structure using three MO-CCCIIs and two grounded capacitors is proposed. The use of MO-CCCII greatly simplifies the structure. The filter exhibits a low input impedance and high output impedance. The output terminals are current sources and hence can easily be cascaded and also the notch and all pass filter responses may be obtained by simply connecting the output nodes. The filter, under all operations, exhibits low active and passive sensitivities. The workability of the proposed structure has been confirmed by PSPICE simulations.

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2 Circuit description

The proposed network (Fig. 1) is based on employing CCCII±. It has high impedance y terminal i.e. $i_y = 0$. Port relationship using standard notations can be represented as $v_x = v_y \pm i_x R_{xi}(I_{0i})$, $i_z = \pm i_x$, where $R_{xi} = V_T/2I_{0i}$, V_T is the thermal voltage, I_{0i} is bias current of CCCII and i = 1, 2, 3. To get MO-CCCII, simply current mirrors are inserted at the output of CCCII (subscripts '+' and '−' are used to show positive and negative current transfers).

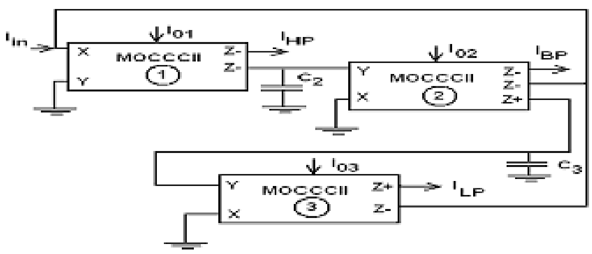

Fig. 1. Proposed universal filter

Routine analysis yields the current transfer functions as

$$G_{LP}(s) = \frac{I_{LP}}{I_{in}} = \frac{1}{D(s)}, \quad G_{BP}(s) = \frac{I_{BP}}{I_{in}} = -\frac{sR_{x3}C_3}{D(s)}$$
$$G_{HP}(s) = \frac{I_{HP}}{I_{in}} = \frac{s^2 R_{x2}R_{x3}C_2C_3}{D(s)} \tag{1}$$

where

$$D(s) = s^2 R_{x2}R_{x3}C_2C_3 + sR_{x3}C_3 + 1 \tag{2}$$

The coefficient of s in Eqn. (2) cannot be equal to zero; hence the circuit is always stable. By adding all the current outputs i.e. I_{LP}, I_{BP} and I_{HP} and treating the node thus obtained as the output node, an all pass filter can be obtained. Similarly, by adding the current outputs I_{LP} and I_{HP} one can obtain a notch filter. No matching constraint is required for all pass and notch responses in contrast to refs. 8 and 16.

The transfer functions of LP, BP and HP are characterized by:

$$\omega_0 = 1/(R_{x2}R_{x3}C_2C_3)^{1/2} \omega_0/Q_0 = 1/(R_{x2}C_2), \quad Q_0 = (R_{x2}C_2/R_{x3}C_3)^{1/2} \tag{3}$$

3 Effect of non-Idealities

In case of non-idealities, port relations of CCCII are modified to

$$v_x = v_y\beta + i_x R_{xi}(I_{0i}), \quad i_z = i_x\alpha \quad \text{and} \quad i_y = 0$$

where $\beta = 1 - \varepsilon_v$, $\alpha = 1 - \varepsilon_i$ with $|\varepsilon_v| \ll 1$, $|\varepsilon_i| \ll 1$ and $\varepsilon_v(\varepsilon_i)$ denotes voltage (current) tracking error.

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Considering the non-idealities outlined above the transfer functions become

$$G_{LP}(s)|_n = \frac{I_{LP}}{I_{in}}|_n = \frac{\alpha_1\alpha_2\beta_2\beta_3}{D_n(s)}, \quad G_{BP}(s)|_n = \frac{I_{BP}}{I_{in}}|_n = -\frac{\alpha_1\beta_2 sR_{x3}C_3}{D_n(s)}$$
$$G_{HP}(s)|_n = \frac{I_{HP}}{I_{in}}|_n = \frac{s^2R_{x2}R_{x3}C_2C_3}{D_n(s)} \tag{4}$$

where

$$D_n(s) = s^2C_2C_3R_{x2}R_{x3} + s\alpha_1\alpha_2\beta_2R_{x3}C_3 + \alpha_1\alpha_2\alpha_3\beta_2\beta_3 \tag{5}$$

The transfer functions are characterized by:

$$\omega_0 = \left(\frac{\alpha_1\alpha_2\alpha_3\beta_2\beta_3}{R_{x2}R_{x3}C_2C_3}\right)^{1/2}, \quad \frac{\omega_0}{Q_0} = \frac{\alpha_1\alpha_2\beta_2}{R_{x2}C_2}, \quad Q_0 = \left(\frac{\alpha_3\beta_3R_{x2}C_2}{\alpha_1\alpha_2\beta_2R_{x3}C_3}\right)^{1/2} \tag{6}$$

The results of active and passive sensitivity analysis of ω_0 and Q_0 are given as

$$S^{\omega_0}_{R_{x2}} = S^{\omega_0}_{R_{x3}} = S^{\omega_0}_{C_2} = S^{\omega_0}_{C_3} = -1/2, \quad S^{\omega_0}_{R_{x1}} = 0,$$
$$S^{Q_0}_{R_{x2}} = -S^{Q_0}_{R_{x3}} = S^{Q_0}_{C_2} = -S^{Q_0}_{C_3} = 1/2, \quad S^{Q_0}_{R_{x1}} = 0$$
$$S^{\omega_0}_{\alpha_1} = S^{\omega_0}_{\alpha_2} = S^{\omega_0}_{\alpha_3} = S^{\omega_0}_{\beta_3} = S^{Q_0}_{\beta_3} = 1/2, \quad S^{\omega_0}_{\beta_1} = 0$$
$$S^{Q_0}_{\alpha_1} = S^{Q_0}_{\alpha_2} = -S^{Q_0}_{\alpha_3} = S^{Q_0}_{\beta_2} = -S^{Q_0}_{\beta_3} = -1/2, \quad S^{Q_0}_{\beta_1} = 0$$

All active and passive sensitivities are low and within 1 in magnitude. Thus the circuit can be regarded as insensitive. The Equation (3) indicates that ω_0 can be adjusted by varying bias current I_{03} without disturbing ω_0/Q_0. The ω_0 and Q_0 are orthogonally adjustable if R_{x2} and R_{x3} are simultaneously adjusted by a common control bias current $I_{02} = I_{03} = I_0$. The Equations (3) and (6) indicate that high values of Q factor will be obtained from moderate values of ratios between passive components i.e. low component spread. These ratios can be chosen as $(R_{x2}/R_{x3}) \approx (C_2/C_3) = Q$. Hence the spread of the component values becomes of the order of $\sqrt{Q}$. This feature of the filter related to the component spread allows the realization of high Q values more accurately compares to the topologies where the spread of passive components becomes Q or Q^2 [17].

4 Comparison

In ref. 15, HP output is obtained through capacitor and BP output is at low impedance port x. Hence to obtain all the standard universal filter functions, either three or four current conveyors are required. If implemented with three conveyors then one of the conveyors has to be double output type.

Survey of literature till date on SITO universal current mode filter revels that four or more conveyors are necessary to implement all the standard universal filter functions (LP, HP, BP, Notch, AP) except in three works [7, 8, 15] where three conveyors are required as that of present work. It revels that our work is comparable with the works of refs. 7, 8, and 15 in term of number of current conveyors used. Hence we compare our work with refs. 7, 8, 15.

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(a) Requirement of passive components:

One or more passive components are ungrounded in [7, 15] which is not suitable for IC implementation [10]. All the CCIIs cannot be replaced by CCCIIs in [7, 8]. Even if one tries to replace, the minimum number of passive components cannot be reduced below three which is one more than the present work.

(b) Matching constraint:

Ref. 8 needs to satisfy a matching condition, in contrast to present work, to yield all pass response (AP).

(c) Orthogonal and electronic control of ω_0 and Q_0.

Orthogonal control of ω_0 and Q_0 is not possible in ref. [8] for AP response. Additional active components (such as FETs) are needed for orthogonal and electronic control of ω_0 and Q_0 in [7, 8]. In the present work, the orthogonal and electronic control do not require any additional active components but can easily be controlled by bias currents (I_{02} and I_{03}) of MO-CCCIIs for all the responses (LP, HP, BP, Notch, AP).

(d) High frequency limitations:

In contrast to the present work, all the three works [7, 8, 15] use capacitor at x port which will limit the higher frequency range of operation [8].

5 Simulations

The universal filter of Figure 1 has been simulated using PSPICE circuit simulation program with DC supply voltage of ± 2.5 V. The simulated and ideal responses of low pass, band pass and high pass are shown in Fig. 2 for $C_1 = C_2 = 10$ nF, $I_{01} = I_{02} = I_{03} = 100\,\mu$A.

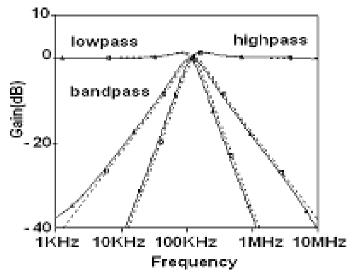

Fig. 2. Low pass, band pass and high pass responses of the proposed filter.
- - - □ - - - Ideal ——— △ ——— Simulated

6 Conclusion

A new universal current mode filter has been presented. The proposed filter uses three MO-CCCII and two grounded capacitors. The filter has the following attractive features (i) use of only grounded capacitors makes the structure less sensitive to parasitic and easier to integrate in contrast to [7, 15], (ii) low active and passive sensitivities, (iii) independent control of ω_o without disturbing ω_o/Q_0 (iv) electronic and orthogonal control of ω_o and

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Q_0, (v) realization of all standard functions of universal filter without any matching constraints (vi) filter exhibits a low input impedance and high output impedance thus filter can easily be cascaded, and (vii) allows high Q with low component spread.

Comparison reveals that the proposed SITO structure has a number of advantages over the works reported in the literature till date.

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