Novel electronically controllable current-mode universal biquad filter

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Abstract: A novel electronically-controllable universal current-mode biquad realisable with only three multiple-output second generation Current-Controlled Conveyors (CCCI), two grounded capacitors and one grounded resistor (which can also be implemented electronically) is presented which offers a number of advantageous features, not available simultaneously in any of the previously known electronically-controllable single-input-multiple-output type CM universal CCCI-based biquads. The proposed circuit is eminently suitable for implementation in both bipolar and CMOS/BiCMOS technologies. The workability of the new biquad configuration has been demonstrated by SPICE simulation results.

Keywords: Current conveyors, current-mode active filters

Classification: Integrated circuits

References

1 Introduction

Fabre, Saaid, Wiest and Boucheron [1] demonstrated that the translinear bipolar implementation of the CCII Fig. 1 (a) has the x-terminal parasitic resistance electronically tunable (as it is given by \( r_x = V_T / 2 I_B \)). The resulting building block referred to as Current-Controlled Current conveyor II (CCCII), characterised by \( i_y = 0, v_x = v_y + i_x r_x \) (where \( r_x = V_T / 2 I_B \)), \( i_x = +i_x \) was used to produce current-controlled current-mode filters whose parameters could be controlled by the external bias currents of the CCCIIIs [1, 2].

Since then, several researchers have proposed electronically-controllable multifunction/ universal current-mode (CM) biquad filters [3-9] which can be classified into two major categories: multiple-input-single-output (MISO) type structures [3, 4] and single-input-multiple-output (SIMO) type structures [5-9]. However, the previously known electronically-controllable SIMO-type universal CM biquads [5-9] suffer from one or more of the following drawbacks (i) non-realisability of all the five standard responses [5, 7-9] (ii) employment of more than three CCCIIIs [5-9] (iii) non-availability of the tunability the filter parameters [5, 7-9] in all the filter realisations and (iv) non-availability of all the current-mode outputs explicitly\(^1\) (i.e. from a high output impedance terminals).

\(^1\)The previously known structures of [5, 7-9] have one or more output currents flowing in grounded circuit elements due to which additional CCs configured as Current followers (with a virtual ground at their input) would be needed to sense out these currents and make them available at high output impedance terminals.
put impedance output terminal) [5, 7-9]).

In this communication, we present a novel SIMO-type electronically-controllable universal biquad configuration which does not have the above mentioned limitations while employing no more than three multiple-output CCCIs (MOCCCIIs), two grounded capacitors and a single grounded resistor. In fact, the new circuit offers features all of which are not available simultaneously from any of the electronically-controlled SIMO-type CCCII-based CM biquads known earlier [5-9].

2 Proposed Configuration

The proposed configuration is shown in Fig. 1 (b). Assuming the MOCCCIIs to be characterised by $i_y = 0$, $v_x = v_y + i_x r_x$, $r_x = V_T/2I_B$, $i_{Z+} = i_x$ and $i_{Z-} = -i_x$, by a straightforward analysis, the three basic functions realised by this circuit are given by

\[
I_{0LP} \left( \frac{\omega_0^2}{D(s)} \right) = I_{in} \quad I_{0BP} \left( \frac{\omega_0}{D(s)} \right) = -I_{in} \quad I_{0HP} \left( \frac{s^2}{D(s)} \right) = I_{in}
\]

where

\[
H_{0HP} = -H_{0BP} = H_{0LP} = \frac{R_0}{R_x3}
\]

and

\[
D(s) = s^2 + \frac{1}{R_x1 C_1} s + \frac{1}{R_x1 R_x2 C_1 C_2}
\]

Using $R_{xi} = \frac{V_T}{2I_B}$, $i = 1 - 3$, the parameters of the realised filters can be expressed as

\[
\omega_0 = \frac{2}{V_T} \sqrt{\frac{I_{b1} I_{b2}}{C_1 C_2}}; \quad Q_0 = \frac{2I_{b1}}{V_T C_1} \quad Q_0 = \sqrt{\frac{I_{b1} C_1}{I_{b1} C_2}}; \quad H_{0HP} = -H_{0BP} = H_{0LP} = \frac{2R_0 I_{b3}}{V_T}
\]

It may be seen that because of the ready availability of the three basic transfer functions (i.e. LP, BP and HP) with correct polarities as well as due to the equal values of all the three gains, a bandstop (BS) function is realisable.
just by joining LP and HP outputs whereas an all-pass function is realisable by joining all the three output terminals. Also, note that no component-matching or equality constraint is needed in any of these two additional realisations. Furthermore, in case of BP/BS, after setting the BW by I_{b1}, \omega_O can be controlled by I_{b2} and finally, H_0 can be independently controlled by I_{b3}. On the other hand, in case of HP/LP, simultaneous variation of I_{b1} and I_{b2} gives constant-Q_0, variable-\omega_O response with H_0 being independently controllable by I_{b3}. Finally, it may be observed that, the new circuit\(^2\) has resistive input impedance which is equal to R_0.

Using \(v_{xm} = \beta_m v_{ym} + i_{xm} R_{xm} \), \(i_{Zmp} = \alpha_{mp} i_{xm} \) and \(i_{Zmn} = \alpha_{mn} i_{xm} \), where \(\beta_m\) represents the non-ideal voltage gain between y and x terminals and \(\alpha_{mp}\) and \(\alpha_{mn}\) represent the gains of the positive and negative z-outputs of the \(m^\text{th}\) MOCCCII; \(m = 1 - 3\), the various non-ideal expressions of the parameters of the realised filters are found to be as follows:

\[
\begin{align*}
\omega_0 &= \sqrt{\frac{\beta_1 \beta_2 \alpha_{1n} \alpha_{1p}}{R_{x1} R_{x2} C_1 C_2}}, \\
Q_0 &= \sqrt{\frac{R_{x1} C_1 \alpha_{1n} \beta_1}{R_{x2} C_2 \alpha_{1p} \beta_2}}; \\
BW &= \frac{\alpha_{1n} \beta_1}{R_{x1} C_1} \\
H_{LP} &= \left(\frac{R_o}{R_{x3}}\right) \left(\frac{\beta_2 \alpha_{3p}}{\alpha_{1n}}\right) ; \\
H_{BP} &= - \left(\frac{R_o}{R_{x3}}\right) \left(\beta_2 \alpha_{3p}\right) ; \\
H_{HP} &= \left(\frac{R_o}{R_{x3}}\right) \left(\beta_2 \alpha_{3p}\right) \\
\end{align*}
\]

From the above, it can be easily verified that the various active (with respect to the non-ideal gains ‘\(\alpha’\) and ‘\(\beta’\)) and passive sensitivities of the various filter parameters (\(H_0, \omega_O, \text{BW} \) and \(Q_0\)) would be within the range \(0 \leq S_F^P \leq 1\) and the circuit, thus enjoys very low sensitivities.

### 3 SPICE simulation results

For SPICE simulation check of the new circuit, a translinear bipolar MOCCCII implementation has been devised from the CCC-II circuit of Fig. 1 (a) which is shown here in Fig. 2 (a). This MOCCCII was realised with HFA3096 mixed transistors arrays and was biased with \(\pm1.5\) V DC power supplies. The SPICE model parameters are shown in Fig. 2 (b).

In Fig. 3 (a) we show the magnitude responses of LP, BP, HP and Notch filters obtained by SPICE simulations with \(C_1 = 1\) nF, \(C_2 = 1\) nF, \(R_0 = 100\) \(\Omega\), \(I_{b1} = I_{b2} = 20\) \(\mu A\) and \(I_{b3} = 100\) \(\mu A\). Electronic tunability of the parameters was also checked: for the values of \(I_{b2}\) changed to 20 \(\mu A\), 110 \(\mu A\) and 200 \(\mu A\), the corresponding values of \(f_0\) were found to be 158.5 kHz, 363.1 kHz and 489.8 kHz respectively (Fig. 3 (b)) while on the other hand, by varying \(I_{b3}\) to 30 \(\mu A\), 65 \(\mu A\) and 100 \(\mu A\), \(H_0\) was found to vary as 0.21, 0.44 and 0.67 (Fig. 3 (c)) respectively. These SPICE simulation results, thus, confirm the workability, as well as electronic tunability, of the filters realisable from the new configuration.

\(^2\)With all electronically-controllable \(r_x’s\) appearing between x-terminals and ground, the input voltage applied at Y-terminals and output currents taken from various z-terminals, all the MOCCCIIs would then be implementing multiple-output transconductance amplifiers (MOTA) and thus, an entirely-MOTA-based version of the proposed circuit is also conceivable.
4 Concluding Remarks

A new SIMO-type electronically-controllable CM universal biquad employing only three MOCCCIIs, two GCs and one grounded resistor was proposed which possesses the following properties: (i) employment of only three CCCIIIs (ii) ability of realising all the five standard functions (iii) availability of current outputs explicitly in all the five cases (iv) employment of both grounded capacitors (v) very low active and passive sensitivities and (vi) electronic tunability of all the three filter parameters - all of which are not available simultaneously in any of the previously known electronically-controllable SIMO-type CCCII-based CM biquads of [5-9]. Note that for an external-resistor-less realisation, the resistor $R_0$ also can be replaced by a translinear current-controlled-grounded-resistance (such as that of [10]) thereby exclusively using BJTs and capacitors only. Such a version of the proposed circuit is, therefore, eminently suitable for IC implementation in bipolar technology and could also be adopted in CMOS/ BiCMOS technologies using appropriate electronically-tunable CCCII structures (e.g. [11, 12]) in conjunction with a CMOS-grounded resistor for $R_0$. 

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**Fig. 2.** (a) Bipolar MOCCCI. (b) Transistor model parameters.
Fig. 3. (a) Magnitude responses of LP/BP/HP/BS filters realised from the new configuration. (b) Tunability of $\omega_0$ with $I_{b1}$. (c) Tunability of $H_0$ with $I_{b3}$.

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