Research Article

Three-Input Single-Output Electronically Controllable Dual-Mode Universal Biquad Filter Using DO-CCCIIs

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This article presents a dual-mode (voltage-mode and current-mode) universal biquadratic filter performing completely standard functions: lowpass, highpass, bandpass, band-reject, and allpass functions, based on plus-type dual-output second-generation, current controlled, current conveyor (DO-CCCII+). The features of the circuit are that the bandwidth and natural frequency can be tuned electronically via the input bias currents: the circuit description is very simple, consisting of merely 2 DO-CCCIIs and 2 capacitors: the circuit can provide either the voltage-mode or current-mode filter without changing circuit topology. Additionally, each function response can be selected by suitably selecting input signals with digital method. Without any external resistors, the proposed circuit is very suitable to further develop into an integrated circuit. The PSPICE simulation results are depicted. The given results agree well with the theoretical anticipation. The maximum power consumption is approximately 1.81 mW at ±1.5 V supply voltages.

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1. INTRODUCTION

An analog filter is an important block and widely used for continuous-time signal processing. It can be found in many fields, for example, communication, measurement and instrumentation, and control systems [1, 2]. One of most popular analog filters is a universal biquadratic filter since it can provide several functions. Nowadays, a universal filter working in current-mode has been more popular than voltage-mode one. Since the last decade, there has been much effort to reduce the supply voltage of analog systems. This is due to the demand for portable and battery-powered equipment. Since a low-voltage operating circuit becomes necessary, the current–mode technique is ideally suited for this purpose. Actually, a circuit using the current-mode technique has many other advantages, for example, larger dynamic range, higher bandwidth, greater linearity, simpler circuitry, and lower power consumption [3, 4]. However, in present, the voltage-mode circuits are still used in some applications.

The CCII is a reported active component, especially suitable for a class of analog signal processing [5]. The fact that the device can operate in both current and voltage-modes provides flexibility and enables a variety of circuit designs. In addition, it can offer advantageous features such as high-slew rate, higher speed, wide bandwidth, and simple implementation [5, 6]. However, the CCII cannot control the parasitic resistance at $X (R_x)$ port so when it is used in some circuits, it must unavoidably require some external passive components, especially the resistors. This makes it not appropriate for IC implementation due to occupying more chip area, high power dissipation and without electronic controllability. On the other hand, the introduced second-generation current-controlled conveyor (CCCII) [7] has the advantage of electronic adjustability over the CCII. Also, the use of dual-output current conveyors is found to be useful in the derivation of current-mode single input three output filters using a reduced number of active components [8, 9].

In many applications, voltage and current-mode circuits are used to be connected which causes some difficulties that can be overcome by using voltage-to-current and current-to-voltage converters at the interface of these circuits. During $V-I$ interfacing, it is also possible to perform signal processing at the same time so that the total effectiveness of the
electronic circuitry can be increased \[10\]. The literature surveys show that the dual-mode universal filter circuit using different high-performance active building blocks such as OTAs \[11–13\], current feedback op-amps (CFOAs) \[14\], current feedback amplifiers (CFAs) \[15, 16\], four-terminal floating nullors (FTFNs) \[16–19\], and current conveyors \[15, 16, 19, 20, 22\] have been reported. Unfortunately, these reported circuits suffer from one or more of following weaknesses:

(i) excessive use of the active and/or passive elements \[10, 14–17, 19–24\];
(ii) require changing circuit topologies to achieve several functions \[11, 12, 15–17\];
(iii) lack of electronic adjustability \[10, 14–17, 19–23\];
(iv) cannot provide completely standard functions \[10, 11, 13, 15, 16, 19, 20, 22\];
(v) cannot provide functions both in voltage and current-modes with the same topology \[13, 15, 17, 19\].

Recently, the realized circuits by using minimum active components are interesting because of their compactness and suitability for fabrication. Current differencing transconductance amplifier (CDTA) and current differencing buffered amplifier (CDBA) are two active elements which were frequently used to realize the circuits. Our survey found that the universal filter circuits using these elements have been reported \[25–29\]. Unfortunately, they operate only either in the current or voltage mode.

This work is arranged to propose a new voltage/current-mode universal biquadratic filter, emphasizing on the use of plus-type DO-CCCIIs. The features of proposed circuit are that the proposed universal filter can provide completely standard functions both in voltage-mode and current-mode without changing circuit topology by appropriately selecting the input signals: the circuit description is very simple, it consists of 2 DO-CCCIIs and 2 capacitors, which is suitable for fabricating in monolithic chip: the filter does not require any external resistor. In addition, the natural frequency and the bandwidth can be tuned electronically by adjusting the bias currents. Its performances are illustrated by SPICE simulations; they show good agreement as mentioned.

### 2. PRINCIPLE OF OPERATION

### 2.1. Dual-output, second-generation, current-controlled, current conveyor (DO-CCCII)

Since the proposed circuit is based on DO-CCCIIs, it will be introduced in this section. Typically, the DO-CCCII is a versatile analog building block which is similar to the conventional current conveyor (CCCII) except that the DO-CCCII has a finite input resistance \(R_X\) at the \(X\) terminal. DO-CCCII has the advantage of electronically adjustability over the CCCII, because it allows the adjustment of \(R_X\) via the bias current \(I_B\) as shown by

\[
R_X = \frac{V_T}{2I_B},
\]

where \(V_T\) is the thermal voltage. The relationship between the voltage and current variables among \(X\), \(Y\), and \(Z\) ports of an ideal DO-CCCII can be described by

\[
i_Y = 0, \quad V_X = V_Y + R_XI_X, \quad i_Z = i_{Z2} = i_X.
\]

### 2.2. Proposed filter

The proposed dual-mode universal filter is shown in Figure 2, where \(I_{B1}\) and \(I_{B2}\) are input bias currents of DO-CCCIIs \(1\) and \(2\), respectively. They are used to control the corresponding parasitic resistances.
Moreover, has gain of 2 is required. In voltage-mode case, where \( \alpha = 0 \), the output voltage is obtained as

\[
V_O = \frac{V_{in3} s^2 C_1 C_2 R_{x1} R_{x2} + V_{in2} (1 + sC_2 R_{x2}) - V_{in3} s C_2 R_{x1}}{s^2 C_1 C_2 R_{x1} R_{x2} + s C_2 R_{x2} + 1}
\]

From (4), the magnitudes of input currents \( I_{in1}, I_{in2} \) and \( I_{in3} \) can be chosen as in Table 2 to obtain a standard function of the network. The circuit of digital selection can be seen in [30].

Substituting intrinsic resistances as depicted in (1), it yields

\[
\omega_0 = \frac{2}{V_T \sqrt{\frac{I_{b1} I_{b2}}{C_1 C_2}}}, \quad \omega_0 = \frac{\sqrt{\frac{C_1 R_{x1}}{C_2 R_{x2}}}}{Q_0} \tag{5}
\]

From (6), by maintaining the ratio \( I_{b1} \), the pole frequency can be adjusted by \( I_{b1} \) and \( I_{b2} \) without affecting the quality factor. In addition, bandwidth (BW) of the system can be expressed by

\[
BW = \frac{\omega_0}{Q_0} = \frac{2 I_{b1}}{V_T C_T}. \tag{7}
\]

We found that the bandwidth can be linearly controlled by \( I_{b1} \). Moreover, it can be seen that the natural frequency can be adjusted orthogonally from the bandwidth by varying \( I_{b2} \). Moreover, in current-mode case due to high output impedance, it is easy cascading in current-mode but in voltage-mode the output impedance is quit low.

### 2.3. Circuit sensitivities

The sensitivities of the proposed circuit can be found as

\[
S_{c_{1,2}}^{s_{V_{in1}}} = \frac{1}{2}, \quad S_{c_{1,2}}^{s_{V_{in2}}} = \frac{1}{2}, \quad S_{c_{1,2}}^{s_{V_{in3}}} = -1, \quad S_{c_{1,2}}^{s_{V_T}} = -1, \quad S_{c_{1,2}}^{s_{V_{in1}} V_{in2}} = -\frac{1}{2}, \quad S_{c_{1,2}}^{s_{V_{in1}} V_{in3}} = 1, \quad S_{c_{1,2}}^{s_{V_{in2}} V_{in3}} = 1, \quad S_{c_{1,2}}^{s_{V_T} V_{in1}} = 1, \tag{8}
\]

Therefore, all the active and passive sensitivities are equal or less than unity in magnitude.

### 2.4. Nonideal case

For nonideal case, the DO-CCCII can be, respectively, characterized with the following equations:

\[
i_{y} = 0, \quad V_X = \beta V_T + R_X I_X, \quad i_{z1} = \alpha i_X, \quad i_{z2} = y i_X. \tag{9}
\]

In the case of nonidea and reanalysis of proposed filter circuit in Figure 2, it, respectively, yields the output voltage and current as

\[
V_O = \frac{s^2 C_1 C_2 R_{x1} R_{x2} V_{in1} + (\beta_1 \beta_2 \alpha_1 \alpha_2 + \beta_1 s C_2 R_{x2}) V_{in2}}{D_n(s)} - \frac{\alpha_2 s C_1 R_{x1} V_{in3}}{D_n(s)}, \tag{10}
\]

\[
I_O = \frac{1}{D_n(s)} \left[ I_{in1} s C_2 R_{x2} i_1 + I_{in2} \alpha_2 \beta_2 i_1 - I_{in3} D_n(s) \right],
\]

\[
V_O = \frac{s^2 C_1 C_2 R_{x1} R_{x2} V_{in1} + (\beta_1 \beta_2 \alpha_1 \alpha_2 + \beta_1 s C_2 R_{x2}) V_{in2}}{D_n(s)} - \frac{\alpha_2 s C_1 R_{x1} V_{in3}}{D_n(s)}, \tag{10}
\]

\[
I_O = \frac{1}{D_n(s)} \left[ I_{in1} s C_2 R_{x2} i_1 + I_{in2} \alpha_2 \beta_2 i_1 - I_{in3} D_n(s) \right],
\]
where
\[ D_{(n)}(s) = s^2 C_1 C_2 R_{X1} R_{X2} + s C_2 R_{X2} + \beta_2 \alpha_1 \alpha_2. \]  

(11)

In this case, the \( \omega_0 \) and \( Q_0 \) are changed to
\[
\omega_0 = \frac{\alpha_1 \alpha_2 \beta_2}{\sqrt{C_1 C_2 R_{X1} R_{X2}}}, \quad Q_0 = \frac{\alpha_1 \alpha_2 \beta_2}{\sqrt{C_1 C_2 R_{X1} R_{X2}}},
\]

(12)

while \( \text{BW} \) is still equal to (7). The sensitivities of the proposed circuit in nonideal case can be found to be
\[
S_{\omega_0}^{C_{1,2}}, C_{1,2}, R_{X1}, R_{X2} = -\frac{1}{2}, \quad S_{Q_0}^{\alpha_1, \alpha_2, \beta_2} = \frac{1}{2},
\]

(13)

Actually, these deviations are very small and can be ignored. Practically, from (10)–(12), \( \alpha, \gamma \) and \( \beta \) originate from intrinsic resistances and stray capacitances in the active elements. These errors affect the sensitivity to temperature and high frequency response of the proposed circuit. From (10), it is found that the current and voltage gains depend on the temperature and frequency variations, then the DO-CCCII should be carefully designed to achieve these errors as low as possible.

3. SIMULATION RESULTS

To prove the performances of the proposed circuit, the PSPICE simulation program was used for the examinations. The PNP and NPN transistors employed in the proposed circuit were simulated by, respectively, using the parameters of the PR200N and NR200N bipolar transistors of ALA400 transistor array from AT&T [31] with parameters tabulated in Table 3. Figure 3 depicts schematic description of the DO-CCCII used in the simulations. The circuit was biased with \( \pm 1.5 \) V supply voltages. Figure 4 shows the –3 dB frequency response of DO-CCCII. \( C_1 = C_2 = 1 \) nF and \( I_{B1} = I_{B2} = 50 \mu A \) are chosen to obtain both intrinsic resistances values of 260 \( \Omega \). It yields the natural frequency of 540.75 kHz, while

Figure 4: The –3 dB frequency response of DO-CCCII.
calculated value of this parameter from (6) is 612.45 kHz. The results shown in Figure 5 are the gain and phase responses of the proposed biquad filter in voltage-mode obtained from Figure 2, where $I_{b1} = I_{b2} = 50 \mu A$. There are seen that the proposed filter in voltage-mode can provide lowpass, highpass, bandpass, band-reject, and allpass functions dependent on selection as shown in Table 1, without modifying circuit topology.

The gain and phase responses of the proposed biquad filter in current-mode are shown in Figure 6, where $I_{b1} = I_{b2} = 50 \mu A$. There are seen that the proposed filter in current-mode can also provide completely standard functions dependent on selection as shown in Table 2.

Figure 7 displays gain responses of current-mode bandpass function with different $I_{b1}$ values. It is shown that the bandwidth of the responses can be adjusted by the input bias current $I_{b1}$. Figure 8 shows gain responses of bandpass function where $I_{b1}$ and $I_{b2}$ are equally set to keep the ratio to be constant and changed for several values. It is found that pole frequency can be adjusted without affecting the quality factor, as depicted in (6). Maximum power consumption is about 1.81 mW.

4. CONCLUSIONS

The dual-mode universal biquadratic filter based on DO-CCCIIs has been presented. The advantages of the proposed circuit are that it performs lowpass, highpass, bandpass, band-reject, and allpass functions dependent on an appropriate selection of three signals in dual-mode: the bandwidth and the natural frequency can be electronically controlled via input bias currents, it is easily modified to use in control systems using a microcontroller [3]. The circuit description...
comprises only 2 DO-CCCIIs and 2 capacitors. With mentioned features, it is very suitable to realize the proposed circuit in monolithic chip to use in battery-powered, portable electronic equipments such as wireless communication systems.

REFERENCES


