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Electronically Tunable Minimum Component Biquadratic Filters for Interface Circuits

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Abstract

In this paper, two new electronically tunable filter configurations are proposed. The proposed filters operate current-mode (CM), voltage-mode (VM), transimpedance-mode (TIM) and transadmittance-mode (TAM). The first configuration realizes second-order VM band-pass and TAM high-pass filter characteristics from the same configuration. The second one realizes second-order TIM band-pass and CM low-pass filter characteristics from the same configuration. They also use minimum number of electronic components (two capacitors and one active component namely; current controlled current difference transconductance amplifier). The workability of the proposed structures has been demonstrated by simulation results.

Keywords: Second-Order Filters, CC-CDBA, Electronic Tunability, Current-Mode Circuits, Interface Circuits

1. Introduction

It is well known that current-mode and voltage-mode are still important integrated circuit (IC) operations [1-3]. Recently, there is a growing interest in transimpedance-mode and transadmittance-mode operations. A current-input voltage-output filter or voltage-input current-output filter is described as an interface circuit connecting a current-mode circuit to a voltage-mode circuit or a voltage-mode circuit to a current-mode circuit, respectively. These interface circuits are needed in many applications where VM and CM circuits are used together. In addition, the other important application area of transadmittance-mode filters are the receiver baseband blocks of modern radio systems [4,5]. Also the outputs of the many digital/analog converters (DACs) are available as current signals. Then the transimpedance-mode filters can be used for conversion of the signals at the outputs of these DACs, simultaneously. Therefore, several TAM- and TIM-type filters are proposed using different-type active components [6-12].

Simplicity, cost reduction, power consumption and versatility are all important for the integrated circuit manufacturers. Therefore, number of the components is an important parameter. Therefore, numerous circuits are proposed in literature that employing minimum number of component [13-17]. However, these filters use at least four electronic components. The proposed filter is compared to the other filters reported in the literature by the use of **Table 1**. According to **Table 1**, the proposed filter has advantages over the proposed filters in Ref [13-14], since it has electronically tunability property and no external resistors.

In this paper, two new second order filter configurations using only single active component and two capacitors are presented. They realize CM, VM, TIM and TAM second order filter characteristics from the same configuration. Similar kinds of circuits in the literature use more than three elements [13-16] (see **Table 1**).

The paper is organized as in the following sections: In the next section, after a short introduction of CC-CDBA,

Table 1. Comparison of the cited references and the proposed filter.

Ref.	Active Element	External Capacitor	External Resistor	Electronic Tunability
[13]	1 CDBA	2	2	No
[14]	1 CDBA	2	2	No
[15]	1 CCII+	2	2	No
[16]	1 CCCII	2	1	Yes
Proposed Filter	1 CC-CDBA	2	0	Yes

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two new filter configurations using CC-CDBA with two capacitors are introduced. Sensitivities and simulation results are discussed in Section 3.

2. Proposed Resistorless Circuit Configurations and Their analysis

In order to accomplish electronic adjustability in CDBA, Maheshwari and Khan have introduced current controlled current controlled differencing buffered amplifier (CC-CDBA) [17]. It has proven to be useful in many voltage-mode and current-mode analog signal-processing applications [17-21]. The circuit symbol of CC-CDBA is shown in **Figure 1** and its terminal equation can be written as follow

$$V_p = R_p i_p, V_n = R_n i_n, i_z = i_p - i_n, v_w = v_z \tag{1}$$

Current controlled CDBA can easily be implemented using bipolar junction transistor (BJT) technologies shown in **Figure 2** [17]. The parasitic input resistances R_p and R_n using BJT implementation for $I_{p,n}(t) \ll 2I_o$ can be obtained as

$$R_p = R_n = \frac{kT/q}{2I_O} = \frac{V_T}{2I_O} \tag{2}$$

where, k is the Boltzman's constant, T is the temperature in Calvin and q is the electron charge; $V_T = kT/q$ is the thermal voltage. Hence, R_p and R_n can be controlled by varying the bias current I_o. In addition to this, the quality factor Q and the undamped natural frequency ω_o depend on R_p and R_n, which makes them electronically adjustable.

Taking the non-idealities of CDBA into account, the above terminal equations can be rewritten as

$$V_p = R_p i_p, V_n = R_n i_n, i_z = \alpha_p i_p - \alpha_n i_n, V_w = \beta V_z \tag{3}$$

where α_p, α_n and β are the current and voltage gains, respectively, and can be expressed as $\alpha_p = 1 - \varepsilon_p$, $\alpha_n = 1 - \varepsilon_n$, $\alpha_\beta = 1 - \varepsilon_v$, with $|\varepsilon_p| \ll 1$, $|\varepsilon_n| \ll 1$, $|\varepsilon_v| \ll 1$. ε_p and ε_n denote the current tracking errors and ε_v denotes voltage tracking error.

The proposed voltage-mode second-order band-pass filter circuit is shown in **Figure 3(a)**. Routine analysis yields the voltage transfer function as follows:

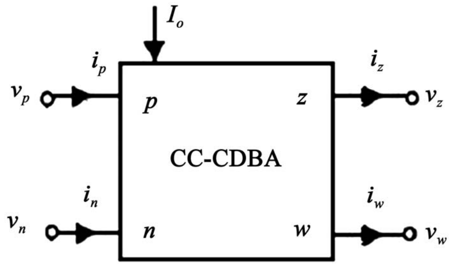


Figure 1. Block diagram of CC-CDBA.

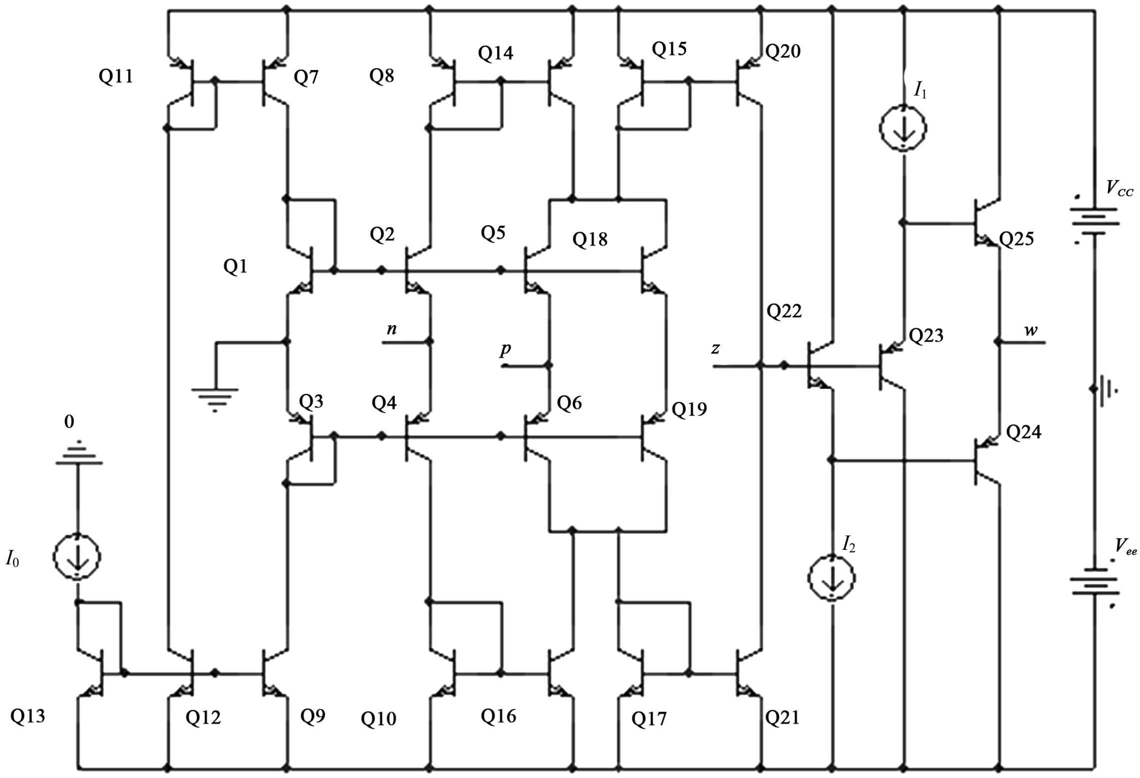


Figure 2. Schematic implementation for CC-CDBA using BJT technology.

$$\frac{V_{out}}{V_{in}} = \frac{sC_1R_n}{s^2C_1C_2R_pR_n + s\left(C_1R_p + C_2R_n\right) + 1} \tag{4}$$

The proposed filter in shown **Figure 3(a)** also gives minimum component transimpedance-mode high-pass filter response. Therefore, the current output response of the proposed circuit is

$$\frac{I_{out}}{V_{in}} = \frac{s^2C_1C_2R_n}{s^2C_1C_2R_pR_n + s\left(C_1R_p + C_2R_n\right) + 1} \tag{5}$$

The proposed current-mode second-order band-pass filter circuit is shown in **Figure 3(b)**. Routine analysis yields the voltage transfer function as follows:

$$\frac{I_{out}}{I_{in}} = \frac{sC_2R_n}{s^2C_1C_2R_pR_n + s\left(C_1R_p + C_2R_n\right) + 1} \tag{6}$$

It also gives minimum component TIM low-pass filter response. Therefore, the voltage output response of the proposed circuit is

$$\frac{V_{out}}{I_{in}} = \frac{R_n}{s^2C_1C_2R_pR_n + s\left(C_1R_p + C_2R_n\right) + 1} \tag{7}$$

The undamped natural frequency and the quality factor of the proposed circuit are obtained from the denominator of the transfer function as follows:

$$\omega_o = \frac{1}{\sqrt{C_1C_2R_pR_n}}, \quad Q = \frac{\sqrt{C_1C_2R_pR_n}}{C_1R_p + C_2R_n} \tag{8}$$

Taking the non-idealities of CC-CDBA given in Equation (3) into account, the denominator polynomial of the transfer function for the proposed filters becomes

$$D(s) = s^2C_1C_2R_pR_n + s\left(\beta\alpha_nC_1R_p + C_2R_n\right) + \beta\alpha_n \tag{9}$$

Using Equation (9), non-ideal the undamped natural frequency and the quality factor becomes

$$\omega_o = \sqrt{\frac{\beta\alpha_n}{C_1C_2R_pR_n}}, \quad Q = \frac{\sqrt{\beta\alpha_nC_1C_2R_pR_n}}{\beta\alpha_nC_1R_p + C_2R_n} \tag{10}$$

From Equation (10), the quality factor Q and the undamped natural frequency ω_o depend on R_p and R_n which can be controlled by varying the bias current I_o. Therefore, they can be adjusted electronically.

3. Sensitivity Consideration and Simulation Results

The ideal sensitivities of the natural frequency and the quality factor with respect to passive components are calculated as follows

$$S_{R_p}^{\omega_o} = S_{R_n}^{\omega_o} = S_{C_1}^{\omega_o} = S_{C_2}^{\omega_o} = -0.5, \tag{11}$$

$$S_{R_p}^{Q} = S_{C_1}^{Q} = 0.5 - C_1R_pk \tag{12}$$

$$S_{R_n}^{Q} = S_{C_2}^{Q} = 0.5 - C_2R_nk \tag{13}$$

where, $k = 1/\left(C_1R_p + C_2R_n\right)$.

If the passive component values are chosen appropriately, the ideal sensitivities will be smaller than 1.

Using Equation (10), the non-ideal sensitivities can be found as

$$S_{\alpha_n}^{\omega_o} = S_{\beta}^{\omega_o} = 0.5, S_{\alpha_p}^{\omega_o} = 0 \tag{14}$$

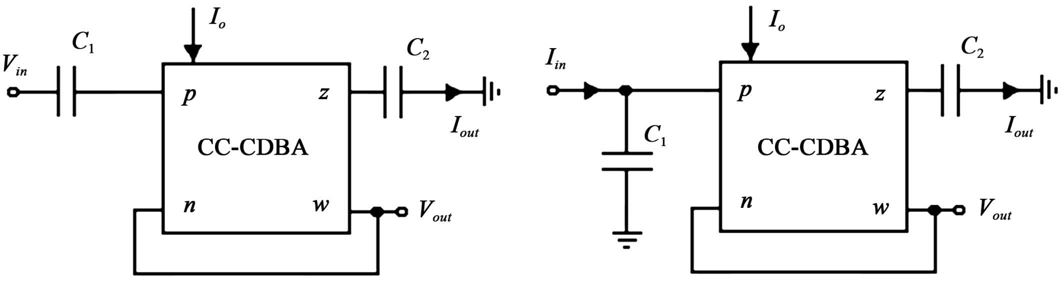
$$S_{\alpha_n}^{Q} = S_{\beta}^{Q} = 0.5 - \beta\alpha_nC_1R_pk \tag{15}$$

where, $k = 1/\left(\beta\alpha_nC_1R_p + C_2R_n\right)$.

Again, if passive component values are chosen appropriately, the sensitivities due to non-ideal effects will also be small than 1.

The performance of the filter topology given in **Figure 3(a)** is verified using PSpice. Each CC-CDBA is realized by its BJT implementation shown in **Figure 2** with the transistor model of PR100N (PNP) and NR100N (NPN) of the bipolar arrays ALA400 from AT & T [22]. In all of the simulations, the voltage supplies of CC-CDBA are taken as $V_{cc} = 2.5$ V and $V_{ee} = -2.5$ V.

To confirm the obtained results with the theoretical results and demonstrate tunability property of the proposed configuration, the gain characteristics obtained by PSPICE for two cases are plotted in **Figure 4** together. In these simulations, bias currents of CC-CDBA are $I_o = 10$ µA and $I_o = 20$ µA, for simulation 1 and 2, respectively.



(a) (b)

Figure 3. Circuit diagram of the proposed filters. (a) VM and TAM filter; (b) CM and TIM filter.

For these simulations, the passive components are taken as $C_1 = C_2 = 1$ nF. These parameters correspond to a BP filter with the with the center frequency $f_o = 124.34$ kHz and $f_o = 248.68$ kHz, quality factor $Q = 0.5$, which are found by using Equation (2) (with $V_T = 25.5$ mV thermal voltage at 25˚C) to find R_p and R_n, and then Equation (8). The simulation results for the voltage-mode band-pass filter shown in **Figure 4**.

From the results predicted by this figure, it is concluded that the simulation results are in good agreement with the theoretical ones over a wide range of frequencies. Although, the two characteristics well coincide over a wide range of frequency, the numerical data reveal the following differences; The maximum peak attenuations for simulation I are −6.41 dB and −6.02 dB, the maximum peak attenuations for simulation II are 6.76 dB and −6.02 dB, the center frequencies for simulation I are 117.34 kHz and 124.34 kHz, the center frequencies for simulation II are 224.78 kHz and 248.68 kHz for simulation and theoretical results, respectively.

Figure 4 also shows that the dependence of the center frequency on the bias current of CC-CDBA is as predicted theoretically; namely when the bias current increases two times its tuning effect appears increasing the center frequency two times.

In order to demonstrate workability of the other output responses, the simulations are also done. For these simulation, the bias currents of CC-CDBA are taken as I_o = 10 µA ($R_p = R_n = 1.3$ kΩ) and the passive components are taken as $C_1 = C_2 = 1$ nF. The magnitude characteristics of the filters which are shown in **Figures 3(a)** and **3(b)** are given in **Figure 5**.

4. Conclusions

In this paper, an electronically tunable VM band-pass, CM band-pass, TAM high-pass and TIM low-pass filters using current controlled CDBA are proposed. The proposed circuit offers the following advantageous features: 1) use of minimum number of electronic active and passive ele-

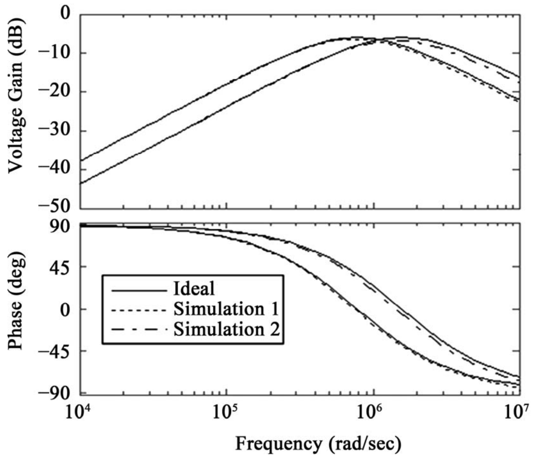
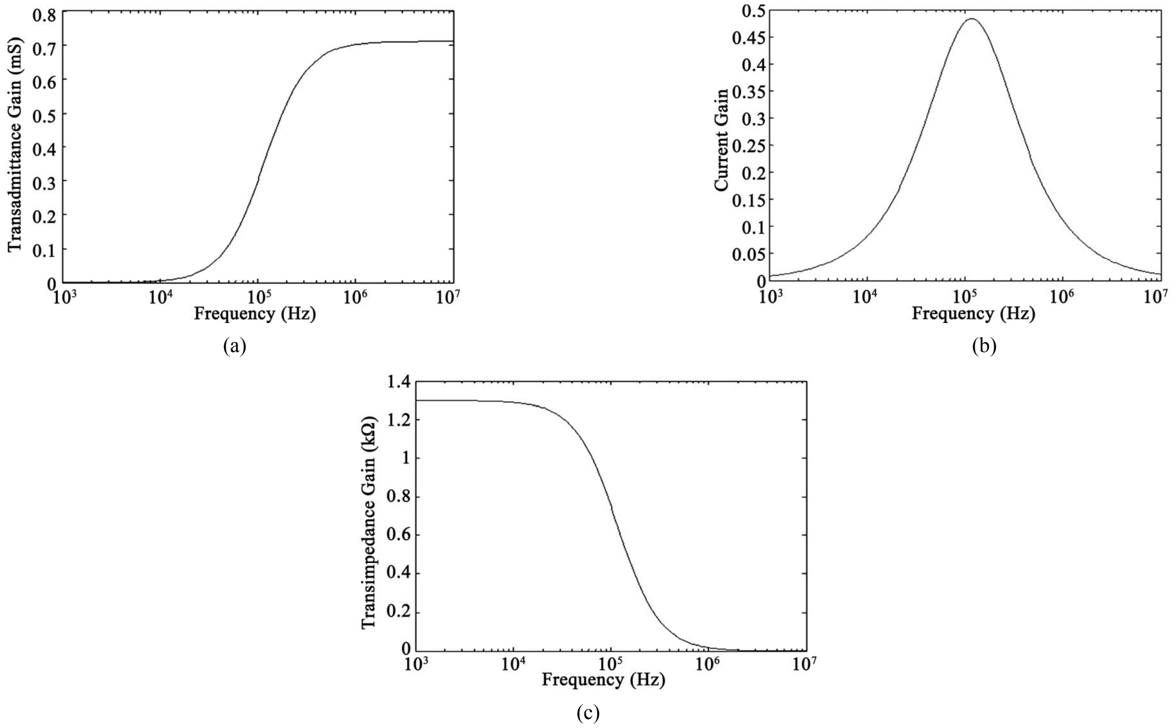


Figure 4. Simulation results for the proposed filter.



(a)

(b)

(c)

Figure 5. (a) The transadmittance grain for the proposed circuit in Figure 3(a); (b) The current gain for the proposed circuit in Figure 3(b); (c) The transimpedance gain for the proposed circuit in Figure 3(b).

ments, namely; two grounded capacitors and one CC-CDBA; 2) the quality factor and natural frequencies can be adjusted electronically without changing the values of the passive components; 3) single active component, which means less power consumption; 4) having one or more advantages over the proposed configurations in the literature [13-16]; 5) low sensitivities; 6) TIM and TAM outputs, this eliminates the need for current to voltage or voltage to current conversions in DAC and ADC applications; The above properties most of which are well verified by the PSpice simulation make the proposed filter attractive for circuit designers and engineers.

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