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Resistorless realization of current-mode first-order allpass filter using current differencing transconductance amplifiers

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A B S T R A C T

This paper presents a realization of a current-mode first-order allpass filter using two current differencing transconductance amplifiers (CDTAs) as the active components and one virtually grounded capacitor as the only passive component. The proposed filer requires no external resistor and is electronically adjustable by varying the external bias current of the CDTA. No component-matching constraints are required. The circuit realizes both inverting and non-inverting types of allpass filters, and also exhibits high-output impedances, which are easy cascading in the current-mode operation. As an application of the proposed CDTA-based allpass section, a current-mode quadrature oscillator is realized. PSPICE simulation results are given to confirm the theoretical analysis.

1. Introduction

It is well known that the first-order allpass filter is widely used in several analog signal-processing applications. In general, it is used for phase shifting from 0° to 180° or from 180° to 0°, while keeping the amplitude of the signal constant over the frequency range of interest. It can also be used to realize universal biquadratic filters, to synthesize quadrature and multiphase oscillators, and to implement high quality-factor frequency selective filters. Current-mode circuits are receiving much attention because of their potential advantages such as wider bandwidth, wider dynamic range, simpler circuitry and lower power consumption. As a result, a number of current-mode first-order allpass filter realizations using different active building blocks were reported in the technical literature [1–12]. However, some of these networks suffer from the use of floating resistors or capacitors [1–6]. The networks reported in [6–8] use a number of passive elements with matching conditions, but provide high impedance outputs suited for current-mode cascading. Furthermore, most of the existed realizations do not include electronically tunability property [1–3,6–11]. Although first-order allpass sections with electronic tuning properties were reported in [4,5,13–15], the current-mode configurations of [4,5] do not exhibit high-output impedance while the works in [13–15] operated in voltage-mode. In [12], an electronically tunable current-mode first-order allpass filter realization was presented, which requires only current differencing transconductance amplifier (CDTA) and three passive components. Moreover, most of them usually realize either non-inverting or inverting types of allpass function [1–5,7–14]. For the realization of the complementary type, they need to change the circuit configuration. In view of above explanation, none of the earlier circuits are able to achieve all the desirable features simultaneously.

This paper presents the resistorless and cascadable current-mode first-order allpass filter employing only two CDTAs and a single-virtually grounded capacitor, which contains a minimum number of components. Due to electronically tunability property of the CDTA, the phase response of the proposed circuit can be adjusted by an external bias current. No component-matching conditions for realizing the allpass functions are required. The circuit can realize both inverting and non-inverting types of current-mode first-order allpass filters without changing circuit topology. The proposed circuit also exhibits high-output impedance, which is easy cascading in the current-mode operation. In view of the literature surveys, a comparison of the previously reported realizations from [1–12] and the proposed circuit introduced in this work is summarized in Table 1. It reveals that the proposed circuit is capable of achieving all the above-mentioned important parameters simultaneously. In order to illustrate the design utility of the proposed CDTA-based allpass section, an application in realizing of a current-mode quadrature sinusoidal oscillator is also given.

2. Circuit description

As shown in Fig. 1, the CDTA is a versatile current-mode active building block where p and n are input terminals, and z and x are

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Table 1
Comparison of proposed allpass filter with previously reported ones.

Allpass filters	Number of active elements	Number of passive elements	Without constraints/ conditions	High output impedance	Grounded/virtually grounded capacitors	Resistorless circuit	Electronically tunable	Realisability of both the allpass types
[1]	1	4	×	✓	×	×	×	×
[2]	1	3	×	×	✓	×	×	×
[3]	1	2	✓	×	✓	×	×	×
[4]	1/2	1	×/✓	×	×	✓	✓	×
[5]	1	2	×	×	×	✓	✓	×
[6]	1	5	×	✓	×	×	×	✓
[7]	2	4	×	✓	✓	×	×	×
[8]	2	3	×	✓	✓	×	×	×
[9]	1	2	✓	✓	✓	×	×	×
[10]	1	2	✓	✓	✓	×	×	×
[11]	1	2	✓	✓	✓	×	×	×
[12]	1	3	✓	✓	✓	×	✓	×
Proposed	2	1	✓	✓	✓	✓	✓	✓

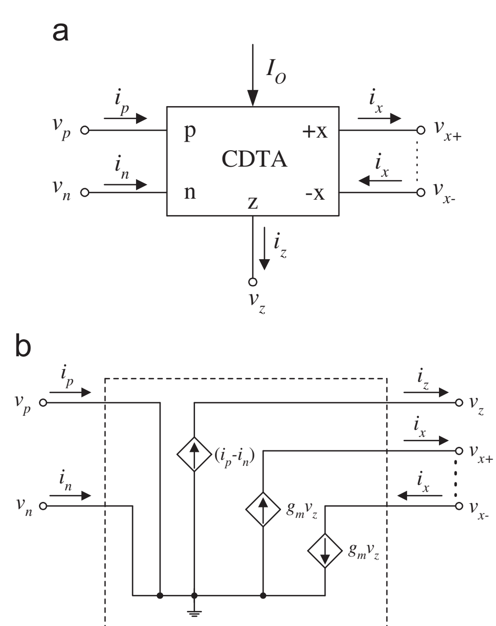

Fig. 1. CDTA: (a) circuit representation, (b) equivalent circuit.

output terminals. The port relations characterizing this device can be described by the following expressions [12,16]:

$$v_p = v_n = 0, \quad i_z = i_p - i_n \quad \text{and} \quad i_x = g_m v_z = g_m Z_z i_z \tag{1}$$

where g_m is the transconductance gain of the CDTA, and Z_z is an impedance connected at the terminal z. From Eq. (1) and Fig. 1(b), the current through the terminal z (i_z) follows the difference of the currents through the terminals p and n ($i_p - i_n$), and flows from the terminal z into an outside impedance Z_z. The voltage drop at the terminal z (v_z) is then transferred to a current at the terminal x (i_x) by a transconductance gain (g_m), which is generally controllable by an external bias current.

One possible bipolar realization of the CDTA circuit used in this work can be shown in Fig. 2 [17,18]. From the circuit diagram, transistors $Q_1 - Q_{11}$ function as an input stage (i.e., the current differencing circuit) followed by a multiple-output transconductance amplifier implemented by using transistors $Q_{12} - Q_{30}$. Thus, in this case, the transconductance gain g_m is directly proportional to the external bias current I_O, which can be written by:

$$g_m = \frac{I_O}{2V_T} \tag{2}$$

where $V_T \cong 26\,\text{mV}$ at 27 °C is the thermal voltage.

Fig. 3 shows the proposed resistorless current-mode first-order allpass filter with electronic tuning properties employing only two CDTAs and one virtually grounded capacitor. Due to internally grounded input terminals of the CDTA, one end of the capacitor C connected in the structure is effectively grounded and the problem associated with this capacitor is not expected. Therefore, the proposed configuration is a canonical structure and is compatible with monolithic implementation. A routine analysis of the circuit using the describing equations given in Eq. (1) yields the following current transfer function:

$$\frac{I_{AP+}}{I_{in}} = -\frac{I_{AP-}}{I_{in}} = \frac{1 - s\left(\frac{C}{g_{m1}}\right)}{1 + s\left(\frac{C}{g_{m1}}\right)}. \tag{3}$$

From Eq. (3), it can be seen that the circuit can realize both non-inverting and inverting type first-order allpass functions. As it is demonstrated in Fig. 3, the proposed CDTA-based allpass section does not require any external passive resistor, and any matching conditions for realizing first-order allpass function. Here, the pole frequency of the circuit is expressed as:

$$\omega_o = \frac{g_{m1}}{C} = \frac{I_{O1}}{2V_T C}, \tag{4}$$

and the phase responses are respectively given by:

$$\phi_{AP+} = -2\tan^{-1}\left(\frac{\omega C}{g_{m1}}\right) \tag{5}$$

and

$$\phi_{AP-} = 180^\circ - 2\tan^{-1}\left(\frac{\omega C}{g_{m1}}\right). \tag{6}$$

Eqs. (5) and (6) show that the proposed allpass filter can provide phase shifting both between $0 - 180^\circ$ and 180°–0°. Moreover, the shifted phase value can be controlled electronically by adjusting I_{O1}.

3. Effects of non-ideal CDTA

In this section, the proposed allpass circuit is studied taking into account the non-idealities of the CDTA. Considering the parasitics and transfer errors, the simplified equivalent circuit