CDTA Based Transimpedance Type First-Order All-Pass Filter

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Abstract: This paper presents a transimpedance type first-order all-pass filter using a single current differencing transconductance amplifier (CDTA) and one each of capacitor and resistor which is the bare minimum requirement for such type of filter. The circuit is free from the realizibility condition and permits electronic and independent adjustment of gain. The simulation results are also included.

Keywords: - All-pass filter, Current differencing transconductance amplifier, Analog signal processing.

1 Introduction

In analog signal processing first order allpass filters are widely used to shift the phase of the input signal from 0 to 180° or from 180° to 0 while keeping its amplitude constant over the desired range of frequency. All-pass filters are also used to implement high Q selective circuits and for the synthesis of multi phase oscillators as well [1-5]. The design of AP filter circuits employing different active devices such as operational amplifiers (OAs), current conveyors (CCs), operational transconductance amplifiers (OTAs), four terminal floating nullors (FTFNs) etc. operating either in current-mode (CM) or in voltage-mode (VM) have been reported in the literature [2-7]. The available literature shows that much attention has not been paid towards the development of mixed-mode active filters as only a few circuits are available [8-13] and none using the recently introduced active device CDTA. A mixed-mode filter (having current-input voltage output or voltage-input current output) is useful as an interface circuit connecting a CM circuit to the VM circuit or VM circuit to CM circuit, respectively. The most important application of mixed-mode filters is the receiver baseband blocks of radio systems [8].

Also the outputs of the many digital/analog converters (DACs) are available as current signals. Then the transimpedance-mode filters can be used both for filtering and conversion of the signals at the outputs of these DACs, simultaneously. CDTA, a new current-mode active building block has two current inputs, two current outputs and possesses electronic tuning through its transconductance gain. CDTA offers several potential advantages namely electronic tenability, free from parasitic input capacitances and wide frequency range of operation [14-17]. The use of CDTA as active component also simplifies the implementation, thereby yielding the circuits with lesser number of passive components as compared to its counterparts leading to compact structures in some applications [18]. The main aim of this paper is to present a novel first-order transimpedance mode all-pass filter using CDTA. Recently reported CM allpass filter [14] uses CDTA and three passive components and the proposed circuit employs a CTDA and only two passive components which is the bare minimum requirement for this class of circuit. The circuit is devoid of any realizibility condition and the gain is electronically tunable independent of phase through the transconductance gain. The workability of the circuit has been checked through PSPICE.

2 Circuit Description

The schematic symbol of the CDTA is shown in Fig. 1. The inputs p and n produce difference current which is transferred to the z terminal and the voltage at the z terminal is converted into a set of output currents by a dual output transconductance stage.

The port relationships characterizing CDTA are given by

$$V_p = V_n = 0,\ I_z = I_p - I_n,\ I_x = \pm gV_z. \quad (1)$$

The routine analysis of the proposed circuit shown in Fig. 2 yields the following transimpedance transfer function:

$$\frac{V_o}{I_{in}} = \frac{1}{g}\frac{Y_1 - Y_2}{Y_1 + Y_2}. \quad (2)$$

By choosing the admittances Y_1 and Y_2 appropriately, two realizations of all-pass filter can be derived.

Case I:

If Y_1=1/R and Y_2=sC, then the transfer function becomes

$$\frac{V_o}{I_{in}} = \frac{1}{g}\frac{1 - sCR}{1 + sCR} \quad (3)$$

The pole frequency, phase and gain is respectively given by:

$$\omega_0 = \frac{1}{RC} \quad (4)$$

$$\phi = -2\tan^{-1}(\omega CR) \quad (5)$$

$$H = \frac{1}{g} \quad (6)$$

Case II:

If Y_1=sC and Y_2= 1/R, then the transfer function becomes

$$\frac{V_o}{I_{in}} = -\frac{1}{g}\frac{1 - sCR}{1 + sCR} \quad (7)$$

The pole frequency, phase and gain is respectively given by:

$$\omega_0 = \frac{1}{RC} \quad (8)$$

$$\phi = \pi - 2\tan^{-1}(\omega CR) \quad (9)$$

$$H = \frac{1}{g} \quad (10)$$

Thus the circuit provides both inverting and non-inverting types of first-order all-pass filter responses only by interchanging C and R without requiring any matching condition. Also from the above equations it is clear that the gain can be tuned electronically by the transconductance gain g without affecting the phase.

3 Non-ideal Analysis

Taking the non-idealities of CDTA into consideration, the terminal relations can be expressed as

$$V_p = V_n = 0, I_z = \alpha_p I_p - \alpha_n I_n, I_x = \pm g V_z$$

where $\alpha_p = 1 - \varepsilon_p$ and $\varepsilon_p \left(|\varepsilon_p| \langle\langle 1\right)$ denotes the current tracking error from p to z, and $\alpha_n = 1 - \varepsilon_n$ and $\varepsilon_n \left(|\varepsilon_n| \langle\langle 1\right)$ denotes the current tracking error from n to z of the CDTA, respectively.

Re-analysis of the circuit in Fig.2 yields the following modified transimpedance equations in the two cases:

Case I:

$$\frac{V_o}{I_{in}} = \frac{1}{g}\frac{\alpha_p - \alpha_n sCR}{\alpha_p + \alpha_n sCR} \quad (11)$$

$$\omega_0 = \frac{\alpha_n}{\alpha_p RC} \quad (12)$$

$$\phi = -2\tan^{-1}\left(\frac{\alpha_p}{\alpha_n}\omega CR\right) \quad (13)$$

$$H = \frac{1}{g} \quad (14)$$

Case II:

$$\frac{V_o}{I_{in}} = \frac{1}{g}\frac{\alpha_p sCR - \alpha_n}{\alpha_p sCR + \alpha_n} \quad (15)$$

$$\omega_0 = \frac{\alpha_n}{\alpha_p RC} \quad (16)$$

$$\phi = \pi - 2\tan^{-1}\left(\frac{\alpha_p}{\alpha_n}\omega CR\right) \quad (17)$$

$$H = \frac{1}{g} \quad (18)$$

From equations (13) and (16) it can be seen that the pole frequency is slightly altered by the effects of CDTA's current tracking errors, however, gain remains unaffected.

The sensitivities of pole frequency to the passive components R,C and the active components α_p, α_n are:

$$S^{\omega_o}_{R,C} = -1$$

$$S^{\omega_o}_{\alpha_p} = -1$$

$$S^{\omega_o}_{\alpha_n} = 1$$

$$S^{H}_{g} = -1$$

which are all equal to 1in magnitude.

4 Simulation Results

The performance of the proposed circuit has been verified by PSPICE simulation results. The CDTA was realized using the bipolar transistor implementation shown in Fig.3. The NPN and PNP transistors used in the circuit were simulated using the parameters of NP100N and PR100N respectively from AT&T [19]. The supply voltages were taken as ±3V and the bias currents are $I_1=I_2=I_3=I_5=100\mu A$.The filter has been designed for a phase shift of 90° at a frequency of 1.59 KHz with the following settings: R= 1KΩ, C = 1nF, g = 1mS. Figs.4 and 5 show the phase and magnitude responses respectively for the allpass filtering signal. Also variation of gain with g is shown in Fig.6. The simulated results obtained agree with the theoretical calculations.

5 Conclusions

In this paper a novel first-order all-pass filter in transimpedance-mode is presented. The proposed circuit employs a single CDTA and only two passive components. The circuit is free of any realizibility condition. The gain of the filter is electronically tunable without affecting the phase. PSPICE simulated results are in conformity with the calculated values.

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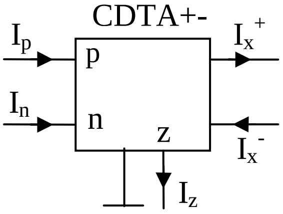

Fig. 1. Schematic symbol of CDTA

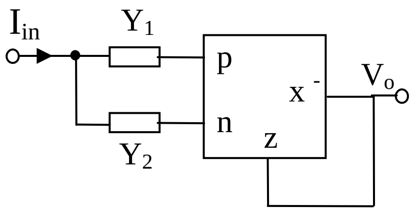

Fig. 2. Proposed TI-mode AP filter

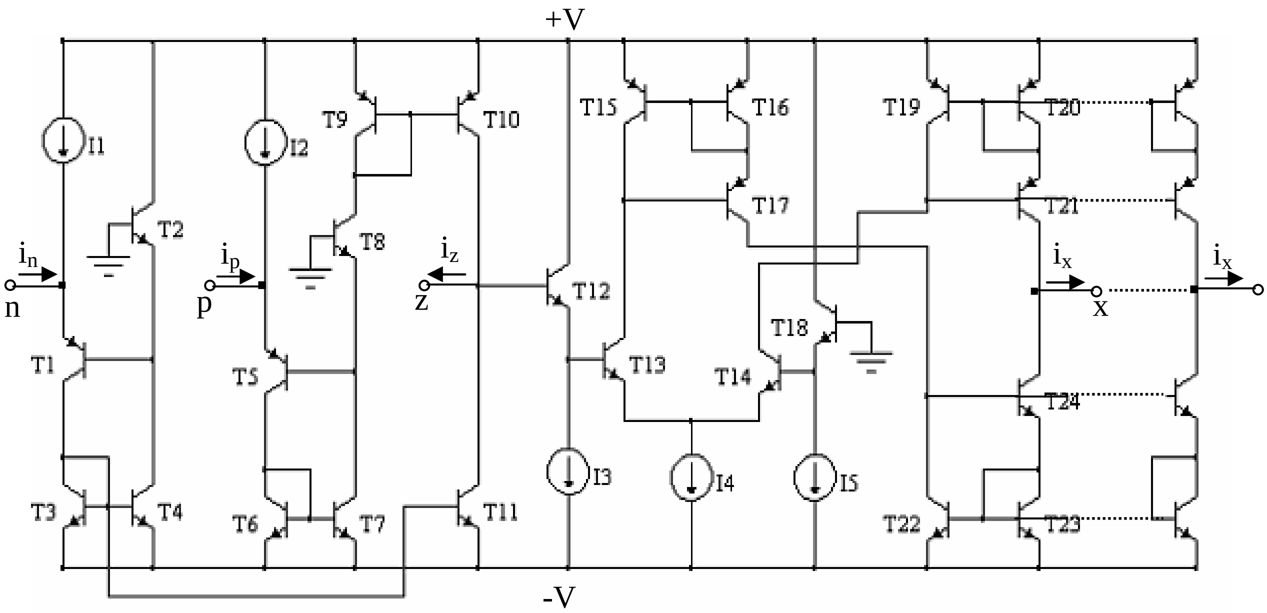

Fig. 3. Bipolar realization of CDTA.

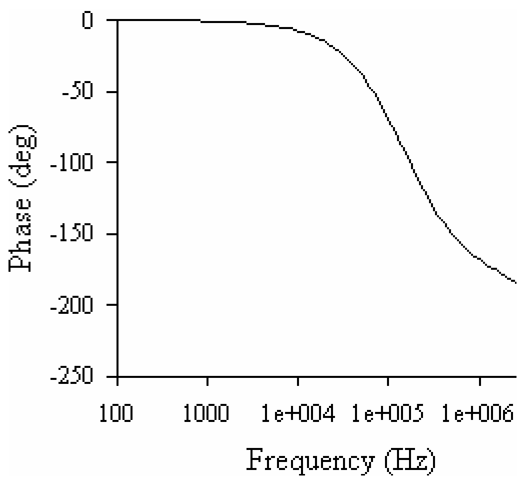

Fig. 4. Phase response of the proposed first-order transimpedance all-pass filter.

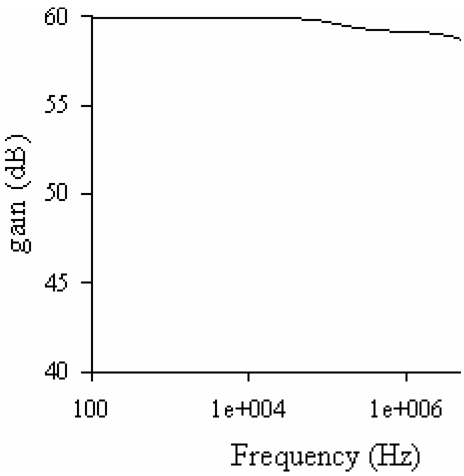

Fig. 5. Magnitude response of the first-order transimpedance all-pass filter.

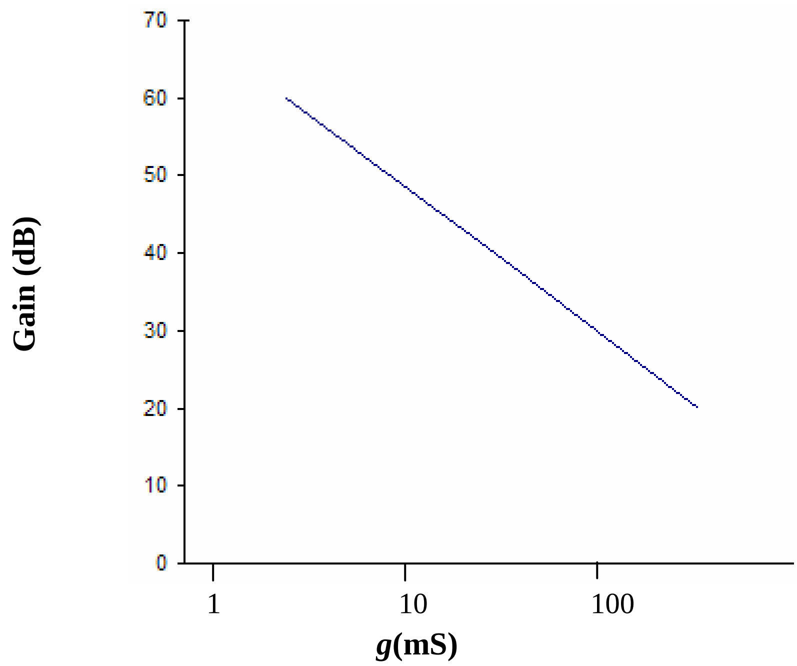

Fig. 6. Variation of Gain with *g*.